Comparative Primary Productivity of Two Flood Control Reservoirs in the Salt Valley Watershed of Eastern Nebraska

John L. Andersen
University of Nebraska-Lincoln

Gary L. Hergenrader
University of Nebraska-Lincoln

COMPARATIVE PRIMARY PRODUCTIVITY OF TWO FLOOD CONTROL RESERVOIRS IN THE SALT VALLEY WATERSHED OF EASTERN NEBRASKA[1]

John L. Andersen and Gary L. Hergenrader
Department of Zoology
University of Nebraska
Lincoln, Nebraska 68508

ABSTRACT: Primary productivity, Secchi disc visibility, chlorophyll, and nutrient concentrations were studied in Wagon Train and Stagecoach reservoirs during the years 1969 and 1970. The reservoirs are separated by a distance of only 12 km and are similar in nutrient content and circulation pattern. Furthermore, in both reservoirs 92-100% of the productivity occurs in the upper two meters. However, the reservoirs differ markedly in their underwater light conditions and, consequently in their primary productivity; Wagon Train Reservoir is turbid due to suspended silt and clay particles while Stagecoach Reservoir lacks this turbidity.

During the summer months blue-green algal blooms occur frequently in Stagecoach Reservoir but only rarely in Wagon Train Reservoir. This appears to be due to the rapid attenuation of light by the suspended silt and clay particles.

In Wagon Train Reservoir, increased primary productivity is usually associated with increased Secchi disc visibility, while in Stagecoach Reservoir, increased primary productivity is often associated with decreased Secchi depths. Inorganic turbidity is an important factor affecting the productivity of Wagon Train Reservoir while algal production itself determines turbidity in Stagecoach Reservoir.

Annual productivity in both study reservoirs, when compared to published values for carbon uptake from other lakes and reservoirs, rates very high. Stagecoach Reservoir fixed 530 g C/m^2/year in 1969 and 834 g C/m^2/year in 1970. Wagon Train Reservoir increased from 148 g C/m^2/year in 1969, a year of high inorganic turbidity, to 453 g C/m^2/year in 1970, a year of reduced inorganic turbidity.

INTRODUCTION

Between 1962 and 1968 the U.S. Army Corps of Engineers built the Salt Valley reservoirs. The reservoirs are all located within a 33 km radius of Lincoln in southeastern Nebraska and provide flood protection for that city and surrounding areas. All are surrounded by fertile soils which support intensive row crop culture and grazing. Since the reservoirs depend upon runoff from agriculture lands as their source of water, the impounded water is rich in plant nutrients. Ten of the reservoirs are larger than 40ha in area; these are used intensively by the inhabitants of eastern Nebraska for recreational pursuits. Several of the larger reservoirs are experiencing eutrophication problems, especially frequent algal blooms and large expanses of rooted aquatic weeds (Hergenrader and Hammer, 1973). In the summer of 1968 a

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study of primary production in the reservoirs was begun and continued through the summers of 1969 and 1970. Two of the study reservoirs, Wagon Train and Stagecoach, although separated by a distance of only 12 km were strikingly different in their water clarity; Wagon Train Reservoir is turbid the year around due to suspended silt and clay particles while Stagecoach Reservoir lacks this turbidity. On the other hand the two reservoirs, with few exceptions, are quite similar in their concentrations of dissolved salts and other parameters (Table 1). This situation presented an opportunity to compare productivity in the reservoirs and relate it to extant underwater light regimes.

Table 1. SUMMER MEANS (June, July, August) of Selected Physical, Chemical and Biological Parameters of the Study Reservoirs

	Wagon Train 1969 (n-15)	Wagon Train 1970 (n=14)	Stagecoach 1969 (n=15)	Stagecoach 1970 (n=14)
Secchi Depth (cm)	28	51	104	69
Phosphate mg/1 PO_4	0.25	0.13	0.22	0.12
NH_3 & NO_3 Nitrogen mg/1 N	1.82	0.38	0.94	0.57
Dissolved Solids mg/1	221	269	231	243
Total Alkalinity mg/1 as Ca CO_3	129	178	130	135
Chlorophyll mg/m^3	19.23	26.20	44.09	89.74
Carbon Uptake mgC/m^2/day	726.48	2836.40	2591.77	5357.03
Turbidity JTU	122	38	22	40

Wagon Train Reservoir was completed in 1962, has a surface area of 128ha, a mean depth of 2.6 meters and drains an area of 4042ha. Stagecoach Reservoir was completed in 1964, has a surface area of 79ha, a mean depth of 3 meters and drains an area of 2513ha. Both of the reservoirs commonly reach surface temperatures of 26-28 C during the summer and neither shows any stable thermal stratification.

METHODS AND MATERIALS

Determinations of primary productivity were made using the *in situ* carbon-14 techniques of Steeman-Nielsen (1952 and later modified by Doty and Oguri, 1959; Strickland, 1960; Goldman, 1963 and Wetzel, 1964). All experiments in both reservoirs were conducted in restricted areas near the dams where the depths ranged between 4 and 5.5m. The samples were incubated for four hours with solar noon the midpoint of the incubation period. Samples were counted with a model 8703 gas flow Geiger-Mueller counter. The absolute activity of the $Na_2C^{14}O_3$ was determined with a Packard Tri Carb Liquid Scintillation Spectrometer series 314E. Productivity was calculated at each sample depth in the lake with the equation described in Vollenweider (1969). These points were then plotted on a graph, the points were connected and the area under the curve was calculated. Conversion of the 4-hour incubation period to day rates was based upon experiments conducted during the lighted period of one day which was divided into nearly equal time intervals. The fraction of the total daily productivity which occurred during our standard incubation period was used in converting all other 4 hour experiments to day rates. Alkalinity and total carbon were determined by the method of Saunders, Trama and Bachmann (1962). All other chemical determinations are described in Hergenrader and Hammer 1973). Underwater illumination was measured with a Chipman underwater photometer, which can detect light down to a level of about one lux. Surface light measurements were obtained from the North Omaha Station of the U.S. Weather Bureau.

Turbidity was measured with a Hach kit (Table 1). However, this method is based on light attenuation and does not differentiate between light attenuated by algal population and light attenuated by suspended inorganic material.

Annual productivity was computed on the basis of measurements taken on Pawnee Reservoir, another of the Salt Valley Reservoirs. This reservoir was studied on a year around basis and summer productivity was found to be 45.0% of annual productivity during 1969 and 57.6% of annual productivity during 1970. Since Stagecoach and Wagon Trail Reservoirs are nearby, we expect the same external climatic influences to affect the reservoirs equally. Assuming that a similar percent of total production occurs in the study reservoirs as occurs in Pawnee Reservoir, summer production values can be converted to annual production values.

RESULTS

The mean levels of nitrogen and phosphorus shown in Table I are above the concentrations usually required to support good algal growth. Vollenweider (1968) suggested that waters containing in excess of .02 mg/1 phosphorus and .30 mg/1 inorganic nitrogen at the beginning of the growing season could be expected to develop algal blooms. In Wagon Train and Stagecoach Reservoirs there was from 6-12 times more phosphorus than the levels suggested by Vollenweider while nitrogen concentrations were 1-6 times greater. Considering the concentrations of these elements now present, high rates of algal productivity would be expected in the reservoirs if other factors were favorable. Intense blooms of the blue-green algae *Anabaena, Aphanizomenon,* and *Microcystis,* do occur each summer in Stagecoach Reservoir causing the water to appear pea-green. In Wagon Train Reservoir these algae seldom grow in any abundance, the dominant forms being diatoms and flagellated green algae.

Because of the shallowness of both reservoirs, the entire water mass circulates. Thus the nutrients released by the degradation of organic matter are available for recycling instead of being lost to a hypolimnion. We have not however, determined the extent to which these nutrients are fixed by the sediments. The major portion of carbon uptake (98-100%) seldom extends below the upper 3m of water. Except on one occasion in both reservoirs C-14 uptake in the uppermost 2m accounted for 92-100% of the total production below one square meter of reservoir surface. Once in Wagon Train Reservoir, during a period of extreme turbidity, 100% of the uptake occurred in the first one meter. A typical vertical profile of C-14 assililation in the reservoirs is shown in Fig. 1. Reduced uptake (surface inhibition) was common in Stagecoach Reservoir but was observed only once in Wagon Train Reservoir. We attribute the lack of surface inhibition to the rapid attenuation of light by the muddy water. On one occasion, after the water clarity had increased, the surface effect became noticeable in Wagon Train Reservoir. Furthermore, whenever fixation rates increased, it was due to greater uptake in the upper two meters of water rather than to an extension in depth of the euphotic zone.

Rodhe (1969) states that some Scandanavian lakes fertilized by domestic and industrial pollution exhibit day rates up to 6000 $mgC/m^2/day$. Wetzel (1966) gives 4950 $mgC/m^2/day$ for Sylvan Lake which is hypereutrophic. Maximum day rates up to 8000 $mgC/m^2/day$ were recorded for Small Jasmunder Bodden (Vollenweider, 1968). Vijayaraghavan (1971) measured day rates of over 15000 mgC/m^2 in some tropical ponds. Stagecoach Reservoir had a maximum daily carbon fixation of 8890 mgC/m^2 for 1970 while Wagon Train had a maximum daily production of 5815 mgC/m^2 for the

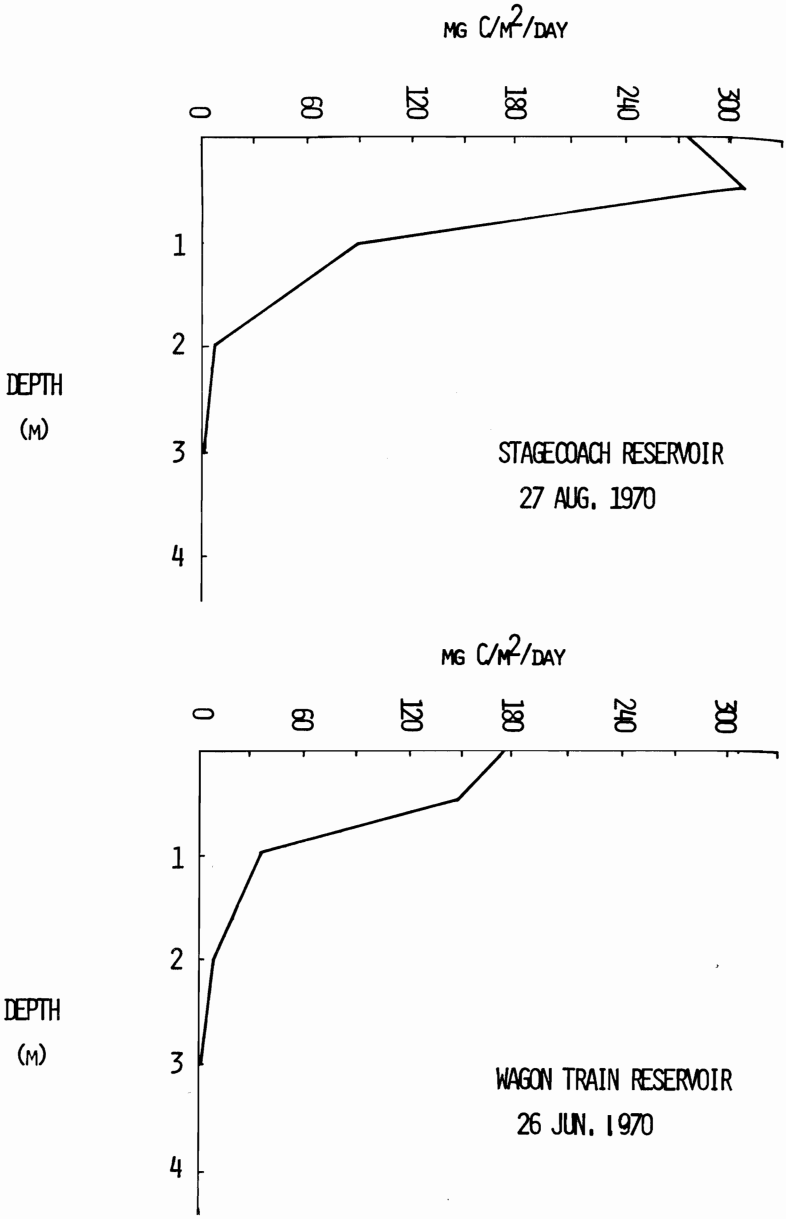

Figure 1. Typical profiles of C^{14} uptake below one square meter of reservoir surface. Surface inhibition was characteristic of series from Stagecoach Reservoir but was observed only once in Wagon Train Reservoir.

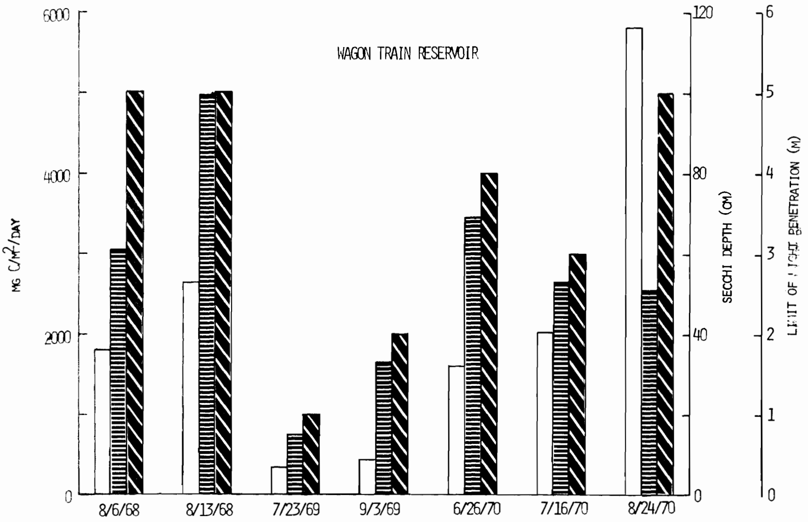

Figure 2. C^{14} uptake (clear bars) Secchi disc depth (horizontal bars) and light penetration (slanted bars) in Wagon Train Reservoir, a reservoir with considerable soil turbidity.

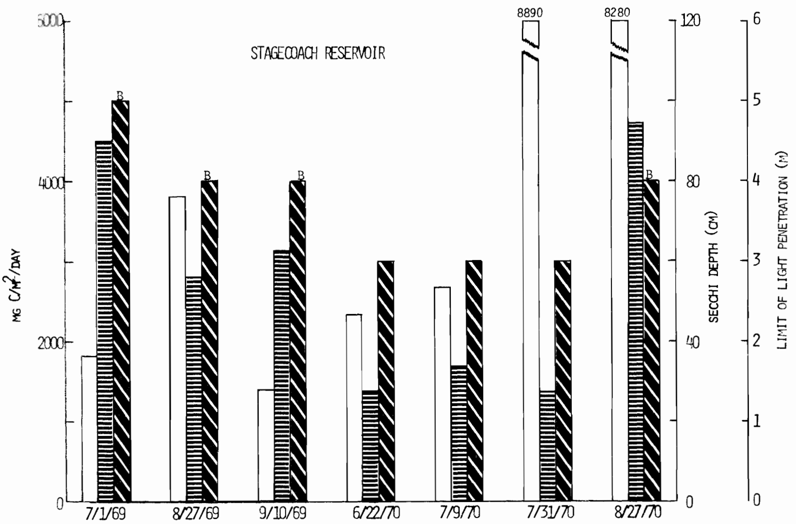

Figure 3. C^{14} uptake (clear bars) Secchi disc depth (horizontal bars) and light penetration (slanted bars) in Stagecoach Reservoir, a reservoir lacking soil turbidity. The letter B indicates that light was still measurable on the reservoir bottom.

same period. Obviously the two study reservoirs exhibit extremely high productivity peaks which are comparable to some of the higher values published for other aquatic systems.

In Fig. 2 the relationship between C-14 uptake, Secchi disc depth, and the limit of light penetration is plotted for each of the experiments in Wagon Train Reservoir. The correlation between productivity and Secchi disc depth is clear. In general, except for the experiment on August 24, 1970, the high rates of production occur during the times of greater Secchi disc visability and the lower rates when Secchi values are minimum. The experiment in August, 1970, does not show good correlation between these variables.

The same parameters depicted in Fig. 2 are shown in Fig. 3 for Stagecoach Reservoir. In contrast to the situation in Wagon Train, however, the higher rates of C-14 assililation are usually associated with reduced Secchi disc depths, the experiment on August 27, 1970, the striking exception. The quantity of light available in the euphotic zone in Stagecoach Reservoir was usually considerably larger than that in Wagon Train Reservoir. In four of the seven C-14 experiments conducted in Stagecoach Reservoir light could still be detected at the bottom of the water column whereas in Wagon Train Reservoir on the seven experimental dates, we could not detect light on the bottom even though the sampling stations in both reservoirs were nearly identical in depth. In both reservoirs light profiles were determined between 1000 and 1200 hours and only when the sun was not obscured by clouds or haze.

If one examines the data in terms of average conditions, some interesting relationships emerge. Between the summers of 1969 and 1970 the Secchi disc depth in Wagon Train Reservoir increased from 28cm to 51cm with a corresponding increase in primary productivity from 726 mgC/m^2/day to 2836 mgC/m^2/day. At the same time the mean chlorophyll concentration increased from 19.23 to 26.20 mg/m^3 (Hergenrader and Hammer, 1973). For the same time period in Stagecoach Reservoir the Secchi disc depth decreased from 104cm to 69cm while primary productivity increased from 2592 mgC/m^2/day to 5357 mgC/m^2/day. The chlorophyll concentration increased from 44.09 to 89.74 mg/m^3. Thus, even though the mean Secchi disc depths between the two reservoirs differed by only 18cm in 1970, primary productivity was nearly twice as great and the standing crop of algae as indicated by chlorophyll was 3.5 times greater in Stagecoach Reservoir than in Wagon Train Reservoir.

The following table from Vollenweider (1968) allows comparison of productivity values from Wagon Train and Stagecoach Reservoirs with productivity values of other lakes around the world.

Lake	Annual Production gC/m²/year	Trophic Classification
Small Jasmunder Bodden	900	Polytrophic
Stagecoach 1970	834	Eutrophic
Large Jasmunder Bodden	780	Polytrophic
Sylvan	580	Eutrophic
Stagecoach 1969	530	Eutrophic
Wagon Train 1970	453	Eutrophic
Lake Norrviken	300	Eu-polytrophic
Schluchsee	180-265	Eutrophic
Furesø	215	Eutrophic
Boden-Rheinsee	130-195	Eutrophic
Esrom Sø	180	Eutrophic
Wagon Train 1969	148	Eutrophic
Erken	105	Meso-eutrophic
Smith Hole	70	Dystrophic
Lunzersee	15-25	Oligotrophic
Traunsee	15-25	Oligotrophic
Krottensee	10-15	Oligotrophic
Altersee	10-15	Oligotrophic

The lakes in the above table are arranged on a highest to lowest scale on the basis of annual production. Since 100 mgC/m^2/day separates oligotrophic from eutrophic lakes, according to Rodhe's (1969) classification, both Stagecoach and Wagon Train Reservoirs can be considered highly eutrophic. It is also obvious that both reservoirs, especially Wagon Train, increased considerably in degree of trophy. Obviously this trend cannot continue indefinitely but it will be interesting to learn at what level a plateau is reached. If the annual productivity of the two study reservoirs is compared with other published values, it can be seen that these reservoirs rate very high on the trophic scale.

DISCUSSION

A number of factors may be cited as reasons for the high productivity in the study reservoirs. Both reservoirs are shallow. Stagecoach Reservoir has a mean depth of 3m and Wagon Train Reservoir has a mean depth of 2.6m. Neither of the reservoirs stratifies indicating that both are well mixed and that nutrients will not be lost to a hypolimnion. Both reservoirs have macronutrients available in large quantities (Table 1). During the summer months, both reservoirs receive large quantities of sunlight, up to 700 or more langleys per day depending on weather conditions, and surface temperatures commonly reach 26-28 C.

Inorganic turbidity is probably the most important factor regulating production in Wagon Train reservoir. On the other hand, in Stagecoach Reservoir algal production seems to regulate turbidity. To the casual observer Wagon Train Reservoir appears muddy while Stagecoach Reservoir during the summer assumes various shades of green.

Biologists have long struggled with the problem of increasing fish production in ponds and reservoirs, particularly in the midwest United States, that commonly have excessive soil turbidity. On the other hand those ponds and reservoirs that lack this turbidity and are normally clear are often troubled with excessive plant production, both algae and rooted aquatic plants. This is to be expected since these impoundments generally rely on surface runoff from the fertile agricultural prairie soils for their water supply. We anticipate that should Wagon Train Reservoir ever become clear of its soil turbidity, it too will develop the same kinds of eutrophication problems now extant in Stagecoach Reservoir. It would appear that one approach to the control of eutrophication problems in these reservoirs would be to investigate substances that could effectively impede light penetration. However, at the same time it would be necessary that such substances not offend the aesthetic sensibilities of the general public. Research in this area could yield far reaching benefits for eutrophication control, particularly in those areas where the more usual controls for eutrophication are impractical.

LITERATURE CITED

Doty, M. S. and M. Oguri. 1959. The carbon fourteen technique for determining primary plankton productivity. Publ. Staz. Napolis, Suppl. 31:70-94.

Goldman, C. R. 1963. The measurement of primary productivity and limiting factors in fresh water with carbon-14. Proc. Conf. Primary Productivity Measurement (1961). USAEC TID-7633.

Hergenrader, G. L. and M. J. Hammer. 1973. Eutrophication of small reservoirs in the great plains. *Proceedings of the International Symposium on Man-Made Lakes, Their Problems and Environmental Effects.* Geophysical Monograph Ser. 17:560-66.

Rodhe, W. 1969. Crystallization of eutrophication concepts in northern Europe. *In:* Proceedings of the International Symposium on Eutrophication (National Academy of Sciences, Washington, D.C.), Madison, Wisconsin. pp. 50-64.

Saunders, G. W., F. B. Trama and R. W. Bachmann. 1962. *Evaluation of a Modified C^{14} Technique for Shipboard Estimation of Photosynthesis on Large Lakes.* Publication No. 8 Institute of Science and Technology. Univ. of Michigan. Ann Arbor, Michigan. 61 pp.

Steeman Nielsen, E. 1952. The use of radioactive carbon (C^{14}) for measuring organic production in the sea. J. Cons. Int. Explor. Mer. 18:117-140.

Strickland, J. D. H. 1960. Measuring the production of marine phytoplankton. Bull. Fisheries Res. Board of Canada. 122:1-172.

Vijayaranghavan, S. 1971. Seasonal variation in primary productivity in three tropical ponds. Hydrobiologia 38:395-408.

Vollenweider, R. A. 1968. Scientific fundamentals of the eutrophication of lakes and flowing waters with particular reference to nitrogen and phosphorus as factors in eutrophication. O.E.C.D. Tech. Report DAS/CSI/68.27 159 pp., 34 figs.

Vollenweider, R. A., (Ed.). 1969. *A Manual on Methods for Measuring Primary Production in Aquatic Environments.* F. A. Davis Co., Philadelphia. 213 pp.

Wetzel, R. G. 1964. A comparative study of the primary productivity of higher aquatic plants, periphyton and phytoplankton in a large, shallow lake. Int. Rev. ges. Hydrobiol. 49:1-61.

Wetzel, R. G. 1966. Variations in productivity of Goose and hypereutrophic Sylvan lakes, Indiana. Invest. Indiana Lakes and Streams. 7:147-184.