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COLLECTION AND ANALYSIS OF BIOLOGICAL DATA FROM THE WOOD RIVER LAKE SYSTEM, NUSHAGAK DISTRICT, BRISTOL BAY, ALASKA

BIBLIOGRAPHY ON EFFECTS OF ARTIFICIAL FERTILIZATION

by

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INTRODUCTION

A review of the literature on the effects of artificial fertilization on natural aquatic ecosystems is presented in this report. Following the summary is an annotated bibliography of studies that used nutrient enhancement as a technique to increase fish production. The final section is a bibliography on the related subjects of phytoplankton, zooplankton, fertilization, and lake management.

Papers chosen for this report were limited to those on fertilization that emphasized production of salmonids in the natural waters (primarily oligotrophic lakes) of North America or temperate and subarctic regions. Studies on pond culture of carp or fertilization of lakes and ponds in tropical regions were excluded. Literature on the relationship of phytoplankton to nutrients, the growth rates of algae in lakes of different trophic types, primary production as related to fisheries, and the description of phytoplankton in some Alaskan lakes were included in the first section of the bibliography. Zooplankton studies were limited to those on feeding and dynamics in relation to phytoplankton. Papers on fertilization of lakes that emphasized subjects other than fish were listed in the bibliography; whereas, lake management studies were limited to those that emphasized nutrients and productivity, but included papers on associated Alaskan lakes.

SUMMARY OF FERTILIZATION STUDIES

Published scientific attempts in North America to increase aquatic productivity by nutrient enhancement began with experiments by Wiebe (1929, 1930). He used organic and inorganic fertilizers and measurements of effects were in terms of plankton production, which was increased by fertilization. Juday and Schloemer (1938) studied the effects of several combinations of inorganic and organic fertilizers added to a small natural lake. They found that both plankton abundance and fish growth rate were increased after fertilization. Smith (1948) fertilized a natural lake with inorganic fertilizers and obtained an increase in plankton production. Ball (1950) discussed the limnological effects of inorganic fertilizers on two natural lakes, then Ball and Tanner (1951) reported on the effects of inorganic fertilizers on plankton, filamentous algae, higher aquatic plants, bottom invertebrates, and fish in a natural, warm-water lake. Both plankton and fish production increased as a result of fertilization. In 1950 Nelson and Edmondson (1955) and Nelson (1959) began fertilizing Bare Lake, Alaska, with commercial nitrate and phosphate fertilizers. Fertilizer was added annually during June - July through 1956. The rate of photosynthesis increased immediately, but there was no significant increase in the abundance of zooplankton; nevertheless, the growth of sockeye salmon fry and smolts increased and the ocean survival of the smolts increased twofold. Tanner (1960) studied the chemical and physical effects of adding inorganic fertilizers to natural lakes. Warren et al. (1964) indicated that production of cutthroat trout increased following an increase in the insect population from stream fertilization with sucrose.

Other earlier fertilization studies tended to ignore aquatic productivity outside that of fish. Gooch (1967) stressed the necessity of assessing the effects of fertilization on fish food. He stated that the absence of sustained studies on the role of artificial fertilization in aquatic productivity made the establishment of predictive principles impossible.

In experiments in a New Brunswick Lake, Smith (1968) determined that increased growth rates of brook trout and rainbow trout occurred following fertilization and predator control. After the fertilization of Fern Lake with inorganic elements (Donaldson et al., 1971) an increase in production of phytoplankton, zooplankton, insects, and rainbow steelhead trout hybrids and sockeye occurred. Parsons et al. (1972) discussed the effects of repeated additions of commercial fertilizer on production in Great Central Lake, British Columbia. All three levels of production increased without changing trophic relationships. Rogers et al. (1973) applied fertilizer to a bay in Lake Aleknagik, Alaska, and found that the abundance of phytoplankton, zooplankton, and insects increased. The average length of sockeye fry in the fertilized area was greater than in unfertilized locations. Volkhonskaya et al. (1973) observed increases in the abundance and biomass of ponds that received mixed fertilization. Qualitative changes in the composition of phytoplankton, zooplankton, and benthos were not indicated.

ANNOTATED BIBLIOGRAPHY

Barraclough, W. E., R. J. LeBrasseur, and C. D. McAllister. 1975. Lake Fertilization: an experimental approach to manipulating food chains. Symposium papers of the Pacific Science Association on Special Symposium on Marine Sciences, 7-16 Dec. 1973, Hong Kong. Edited by B. Morton, published by PSA, Hong Kong, p. 11-12.

Commercial grade fertilizers were added to an oligotrophic lake at a rate intended to maintain winter nutrient supply levels throughout the growing season for primary producers. The phytoplankton standing stock increased threefold, while the zooplankton standing stock increased five to tenfold. (Parsons et al. [1972] - *see* p. 4 of this report - state that phytoplankton standing stock was the same as in the previous year when no fertilizer was added.) The growth in weight of juvenile sockeye salmon was doubled.

Barraclough, W. E. and D. Robinson. 1972. The fertilization of Great Central Lake III. Effect on juvenile sockeye salmon. Fish. Bull. 70(1):37-48.

Underyearling sockeye salmon grew 30% larger in 1970 than in 1969 as a result of adding 100 tons of fertilizer to Great Central Lake. The increase in size was not as great as expected from the increase in quantity of food organisms. This discrepancy may be caused by avoidance of high temperatures by the fish, which then miss the high epilimnetic concentrations of zooplankton.

Donaldson, L. R., P. R. Olson, S. Olsen, and Z. F. Short. 1971. The Fern Lake studies. Coll. of Fish., Univ. of Wash., Contr. No. 352.

An inventory of the natural resources followed by a study of the essential elements as identified by their unstable isotopes was executed on the Fern Lake watershed, Kitsap County, Washington. A mixture of twelve inorganic elements was added to the lake in 1965 and 1968. Nitrogen and phosphorus were added in 1969. The highest level of primary production occurred in 1970, a year without fertilization. Zooplankton production during 1965 and 1968 showed marked increases over the previous and intervening years. Insect production dropped slightly in 1966 and sharply in 1967, but increased greatly from 1968 to 1970. Rainbow steelhead trout hybrids were planted in the lake in 1969. Rapid growth occurred in the spring of 1970 when the abundance of bottom insects was the highest. Sockeye that were planted in 1970 grew rapidly, an indication of good feeding conditions.

Hall, D. J., W. E. Cooper, and E. E. Werner. 1970. An experimental approach to production dynamics and structure of freshwater animal communities. Limn. and Ocean. 15(6):839-928.

The effects of three levels of inorganic nutrients and two predator densities on aquatic animal communities were examined in a series of twenty freshwater ponds. A randomized block design was used for cross-classification of the treatments. Analyses of the three-year study include community composition, secondary production, and a description of fish populations and their feeding behavior.

LeBrasseur, R. J. and O. D. Kennedy. 1972. The fertilization of Great Central Lake II. Zooplankton standing stock. Fish. Bull. 70(1):25-36.

The dominant zooplankton species were studied over distance, depth, and time in relation to a series of nutrient additions to Great Central Lake. Fertilization produced no changes in the species composition.

The average biomass from May to October exceeded 5 g/m^2, more than ten times greater than for the comparable period in 1969, before the fertilizer was added. The temperature structure of the lake may reduce the availability of the zooplankton, preventing efficient utilization by the juvenile sockeye salmon.

Nelson, P. R. 1959. Effects of fertilizing Bare Lake, Alaska, on growth and production of red salmon. Fish. Bull. U.S. Fish and Wildlife Service 60(159):59-86.

Bare Lake, Kodiak Island, Alaska, was fertilized each year from 1950 to 1956. Fertilization was accompanied by increased growth of young red salmon during lake residence. A close relationship was found between the freshwater growth of red salmon and the gross rate of photosynthesis during periods which would influence the food supply. An increase in the size of smolts did not cause an increase in the percentage of younger smolts in the seaward migrations. The increase in size of smolts was followed by an increase in their survival at sea. Threespine stickleback did not respond to fertilization by increased growth. Other factors such as population biomass, incidence of diseased red salmon, or water temperatures had no influence on the growth of juveniles and smolts from 1950 through 1956.

Nelson, P. R. and W. T. Edmondson. 1955. Limnological effects on fertilizing Bare Lake, Alaska. Fish. Bull. U.S. Fish. and Wildlife Service. 56(102):22 (p. 415-436).

Bare Lake was treated on seven different occasions from 1950 to 1954 with commercial nitrate and phosphate fertilizers. The effect of fertilization on the rate of photosynthesis was immediate, increasing by a factor of 2.5 to 7 in the 10-day period after enrichment. The transparency decreased from 6 to less than 2 meters and the pH increased from 7.0 to a high of 9.0. Copepods did not show a significant increase in population size from 1950 to 1952, perhaps as a result of their long life cycle and effective predation. Egg production was accelerated in some rotifers. Each year after fertilization, salmon leaving the lake were longer and heavier than the year before.

Parsons, T. R., C. D. McAllister, R. J. LeBrasseur, and W. E. Barraclough. 1972. The use of nutrients in the enrichment of sockeye salmon nursery lakes (a preliminary report). Marine Pollution and Sea Life, FAO Conference, Rome, Italy, Dec. 9-18, 1970. Fishing news (Books) Ltd., 110 Fleet Street, London, EC4A2JL England. (p. 519-25) 623 p.

Small, frequently repeated additions of soluble fertilizers increased all three levels of production in Great Central Lake, British Columbia, without changing trophic relationships. No decrease in the water quality of the oligotrophic lake occurred following enrichment.

Cyclotella sp. and an unidentified flagellate were the principal species involved in the increase in primary production. All species of zooplankton increased in number. The growth rate of zero and one-year-old sockeye salmon fry increased sharply.

Parsons, T. R., K. Stephens, and M. Takahashi. 1972. The fertilization of Great Central Lake. I. Effect of primary production. Fish. Bull. 70(1):13-23.

Ammonium phosphate and ammonium nitrate were added to Great Central Lake at a rate of 5 tons per week from May to October 1970. Surface primary production was increased tenfold while the euphotic zone primary production was doubled. The standing stock of primary producers was the same as the previous year prior to fertilization. The phytoplankton species were similar in the fertilized and unfertilized areas of the lake. It was concluded that primary production was increased without changing the pathways of production.

Smith, M. W. 1968. Fertilization and predator control to increase growth rate and yield of trout in a natural lake. J. Fish. Res. Bd. Can. 25(10):2011.

Crecy Lake, New Brunswick, was enriched in 1946 with commercial fertilizers thus increasing the growth rates of native and planted brook trout. In 1959, when underyearling and yearling rainbow trout were planted instead of brook trout, the rainbow trout grew faster than brook trout of comparable size. This increase followed intensified predator control and a third fertilization.

Rogers, D. E., D. M. Eggers, and L. G. Gilbertson. 1973. Wood River sockeye salmon studies. 1972 Research in Fish. Coll. of Fish., Univ. of Wash., Contr. No. 375:17, 18.

Bear Bay, in the lower end of Lake Aleknagik, Bristol Bay, Alaska, was fertilized in 1970 with 1,200 lb. of diammonium phosphate. The ratios between the annual means of measurements taken at other unfertilized locations in the lake were used in evaluating the effect of the fertilization. The density of phytoplankton was doubled during 1970. In 1971 the abundance of aquatic insects was increased fourfold and the abundance of zooplankton was increased twofold. During mid-July 1971, the average length of sockeye salmon fry in Bear Bay was greater relative to other locations. Based on the average beach seine catch of fry per adult spawner, the survival from eggs to fry increased after fertilization.

Takahashi, M. and F. Nash. 1973. The effect of nutrient enrichment on algal photosynthesis in Great Central Lake, British Columbia, Canada. Arch. Hydrobiol. 71(2):166-182.

Two situations, fertilized and unfertilized, were simulated for Great Central Lake using a computer model.

Volkhonskaya, N. I., E. B. Savateeva, A. P. Gladkikh, A. P. Pornanova, and M. B. Strugach. 1973. The food supply of Arctic ponds (Kandalaksha fish farm) and the effect on it of fertilizers. Transl. Ser. Fish. Res. Board Can. 2763, 10 p.

The researchers observed changes induced in the food supply of Atlantic salmon juveniles by the addition of organic and mixed fertilizers to arctic ponds. The study did not reveal postfertilization changes in the qualitative composition of phytoplankton, zooplankton, or benthos. Considerable increase was evident in the abundance and biomass of ponds receiving mixed fertilization.

Warren, C. E., J. H. Wales, E. E. Davis, and P. Doudoroff. 1964. Trout production in an experimental stream enriched with sucrose. J. of Wildl. Management 28(4):617-660.

Three experiments were performed from 1960 through 1963 on the production, food habits, and food consumption of coastal cutthroat trout in sucrose-enriched and in unenriched sections of Berry Creek, Oregon. Enrichment with sucrose led to large and consistent increases in food consumption and trout production. The data indicate that the increases are a result of the greater abundance of aquatic food organisms, especially chironomid larvae, in the enriched sections.

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