EFFECTS OF HYDRAULIC DREDGING ON THE ECOLOGY OF NATIVE TROUT POPULATIONS IN WISCONSIN SPRING PONDS

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COVER:
For many anglers spring ponds offer an opportunity to fish for wild trout in solitude.

Abstract

Since 1967 the Wisconsin Department of Natural Resources has been dredging spring ponds to increase living space for native trout populations, mostly brook trout (*Salvelinus fontinalis*), and to restore or enhance sport fisheries. This study, conducted from 1967-75, describes the effects of hydraulic dredging on important physico-chemical characteristics of spring ponds, with particular reference to changes in trout populations, fishing pressure, and harvest. Krause and Sunshine Springs were intensively studied for two years before dredging and four to five years afterwards. Trout populations and harvest in several other dredged and undredged ponds were monitored to provide data for additional comparisons.

Intensively studied ponds were 0.3 to 0.4 ha in surface area and dredging increased volumes by 400 to 500 percent. After removal of organic sediments, marl substrates predominated and areas of exposed mineral soils increased. Ground water was the major water source for both ponds. At Krause Springs dredging did not affect ground water input while in Sunshine Springs, discharge increased by 41 percent. Water temperatures in ponds were not significantly influenced by dredging nor were there any appreciable changes in concentrations of dissolved materials. Dredging completely eliminated aquatic macrophytes and plant recolonization proceeded slowly. In Sunshine Springs, biomass of *Chara* reached about 10 percent of predredging levels after five years.

Densities of benthic organisms were severely reduced by dredging. Tubificids recolonized rapidly and became the most numerous taxa. Prior to dredging, tubificids accounted for about 4 percent of all organisms and four to five years after dredging they comprised 56 to 70 percent of all benthic organisms. With the exception of tubificids and *Gammarus* in Sunshine Springs, none of the other taxa attained predredging levels five years after dredging. Combined densities of all taxa in Krause Springs reached 50 percent of predredging values and those in Sunshine Springs reached 300 percent. Densities of *Daphnia* and *Bosmina* increased after dredging, but did not affect food resources of adult trout.

Structures of fish communities were temporarily altered by dredging; trout accounted for most of the total fish biomass. In shallow ponds trout densities fluctuated greatly because of large-scale emigrations and immigrations. After dredging, emigrations were much reduced. The standing crop of brook trout in Krause Springs changed little after dredging, because numbers of trout hatched in the pond annually, did not appreciably increase. Conversely, at Sunshine Springs there was a marked increase in recruitment and five years after dredging trout biomass was nearly triple that of predredging levels (36 vs. 90 kg/ha). Brown trout (*Salmo trutta*), all of which were emigrants, accounted for more than half of the biomass increase.

Benthic organisms were the primary foods of trout. When benthic densities decreased due to dredging, growth rate of trout declined. As benthic communities recolonized, trout growth rates also increased.

Fishermen utilization increased at both ponds after dredging. At Krause Springs fishing pressure increased from 100 to 489 hours/ha and catch increased from 18 to 152 trout/ha. Fishing pressure at Sunshine Springs went from 94 to 896 hours/ha and catch from 69 to 481 trout/ha. In other dredged and unaltered ponds, fishing pressure ranged from 400 to 2,300 hours/ha and catch ranged from 200 to 1,400 trout/ha. Compared to other small lakes containing salmonids, standing crops and yields of trout from Wisconsin spring ponds were among the highest reported values.

Dredging costs ranged from \$0.52 to \$2.07 to increase pond volumes by 1 m^3, and were inversely related to pond area. Dredging appeared to be an economically sound program on the basis of increased fishermen utilization.

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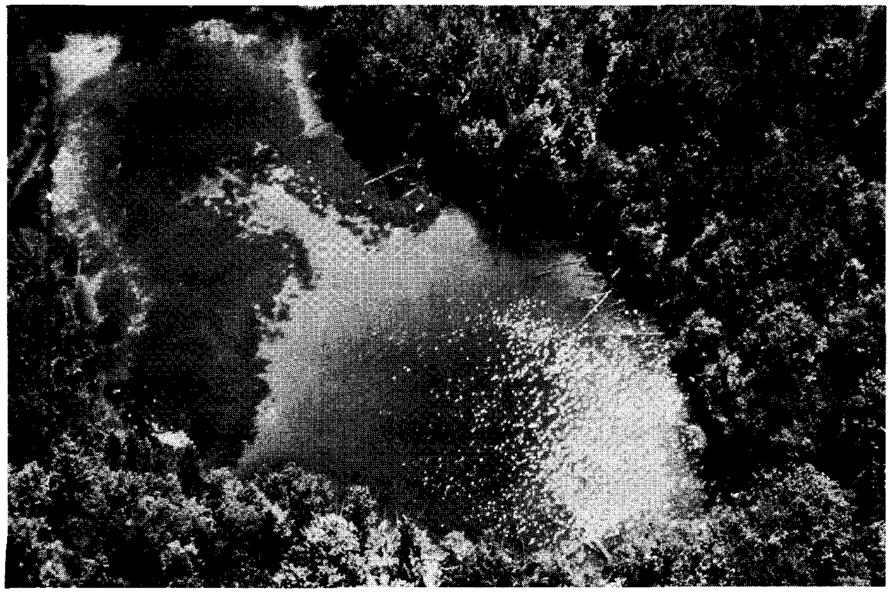
INTRODUCTION

Wisconsin offers a wide variety of trout fishing opportunities. One segment of the trout fishery resource appears to be unique to the state— spring ponds. These small bodies of water, located in remote wooded areas, support populations of wild brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*), are relatively productive, and in general, provide a high quality fishing experience. Recognizing the value of this resource, the Wisconsin Department of Natural Resources (DNR) has actively pursued a program for the acquisition, preservation, and management of spring ponds.

To distinguish spring ponds from other bodies of water, we have chosen the following criteria: (1) surface area is less than 4 ha; (2) major water source is from springs, though inlets may be present; (3) major water loss is through well-defined outlets; and (4) hydrologic exchange time or flushing rate is usually less than 10 days. Within the 30 counties across the northern half of Wisconsin, there are about 1,700 such ponds with a total area of about 1,600 ha that meet the first three of the above criteria. Those ponds that have a relatively rapid exchange of water and sufficient living space support or are capable of supporting trout year-round.



The bed of Chara in this pond is clearly delineated. These plants enhance productivity of invertebrates that comprise an important part of trout diets.

All lakes continually fill in and eventually will develop bog-like conditions. This natural evolution of lakes is dramatically manifested in small bodies of water such as spring ponds. In many ponds there has been extensive shoreline encroachment plus natural filling, hence present surface areas and depths are much reduced, compared to original pond dimensions. Loss of pond area and depth has important management implications, because production of trout in spring ponds is largely dictated by available living space and the degree of filling that has occurred.

In 1967 the DNR initiated a dredging program to reverse this natural aging process in spring ponds and to restore or enhance these trout fisheries. It was recognized that dredging was costly, that it would have drastic effects on pond environments, and that documentation of these effects would be necessary. Therefore, in 1967 research was initiated to provide the needed documentation. Nearly every facet of pond ecosystems and parts of surrounding terrestrial systems were to be affected by dredging. However, our study was designed to examine the effects of dredging on important physico-chemical and biological features of spring ponds, with particular reference to the trout populations and the sport fishery they support. The research reported here was conducted from fall, 1967 to fall, 1975.

Our basic approach was to monitor major physical and biological features of two spring ponds for 2 to 3 years prior to dredging and for 4 to 5 years after dredging. In addition, we studied trout populations and harvest in several other spring ponds. Some of these had been dredged and were chosen so as to provide a larger data base with which to determine the potential productivity of altered ponds. Several unaltered spring ponds were also studied to provide comparisons with dredged ponds. At times our research extended beyond dredging considerations; these related studies have been summarized in other reports (Carline 1972, 1975, and Carline et al. 1976).

DESCRIPTION OF STUDY AREAS

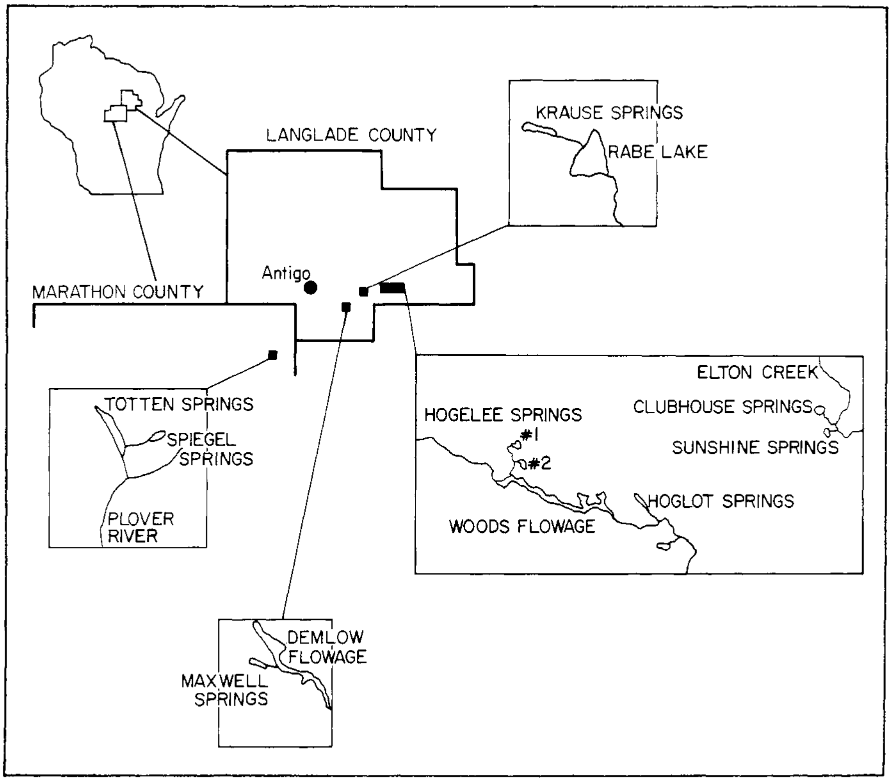


FIGURE 1. *Locations of selected spring ponds.*

Spring ponds included in this study are located in south central Langlade and northeast Marathon Counties (Fig. 1). The City of Antigo, which is 9 to 20 km from the study sites, is situated on a glacial outwash plain that is bordered on the northeast and southeast by terminal moraines and on the west by a ground moraine (Harder and Drescher 1954). Ground water flows through the glacial till of the moraines, which have a relatively high permeability. Spring ponds exist wherever kettle depressions extend below the ground water table of the moraines.

Spring ponds are usually situated at the headwaters of trout streams. Frequently they are surrounded by wooded lowlands dominated by white cedar (*Thuja occidentalis*), tamarack (*Larix laricina*), balsam fir (*Abies balsamea*) and speckled alder (*Alnus rugosa*). Access to ponds is poorly developed in most areas and there is usually limited human habitation nearby. Because of their remoteness, agriculture and logging probably have had little impact on most spring ponds.

TABLE 1. *Locations and physical characteristics of selected spring ponds.*

Ponds	County and Township	Surface Area (ha)	Maximum Depth (m)	Mean Depth (m)	Year Dredged	Species of Trout	Spawning Conditions and Trout Migrations
Study Ponds							
Krause Springs	Langlade Polar	0.36	3.66	1.68	1971	Brook	Limited spawning area Extensive immigrations
Sunshine Springs	Langlade Evergreen	0.38	3.66	1.68	1970	Brook Brown	Moderate spawning area Extensive immigrations
Reference Ponds							
Hogelee Springs #1	Langlade Polar	0.91	2.44	1.63	1969	Brook	Large spawning area Extent of migrations unknown
Hogelee Springs #2	Langlade Polar	0.79	2.44	1.65	1969	Brook	Large spawning area Extent of migrations unknown
Rabe Lake	Langlade Polar	2.51	3.66	1.55	1967-68	Brook Rainbow*	No spawning areas Extensive immigrations
Spiegel Springs	Marathon Plover	0.40	1.98	0.68	1963	Brook Brown	Large spawning areas Extensive migrations
Hoglot Springs	Langlade Evergreen	0.38	1.68	0.64	1963	Brook	Moderate spawning area Extensive immigrations
Clubhouse Springs	Langlade Evergreen	0.81	4.27	1.11	–	Brook Brown	No spawning areas Extensive immigrations
Maxwell Springs	Langlade Norwood	0.97	5.18	0.86	–	Brook	Large spawning area No extensive migrations

*Stocked by DNR, and some escaped from a private fish hatchery.

Krause and Sunshine Springs were monitored intensively before and after dredging; throughout this report they will be called study ponds and all others will be referred to as reference ponds (Table 1). Krause Springs flows into Rabe Lake via a 150-meter outlet. Rabe Creek drains Rabe Lake and joins the Little West Branch of the Wolf River. Woods Flowage is a long, narrow body of water with several spring ponds draining into it, including Hogelee Springs #1 and #2 at the western end of the flowage and Hoglot Springs at the eastern end. Clubhouse and Sunshine Springs flow into Elton Creek, a tributary of the Evergreen River. Maxwell Springs enters Demlow Flowage, which in turn joins the Red River. All of the above waters are located in Langlade County and are part of the Wolf River drainage. Speigel Springs, Marathon County, flows into Totten Springs and then into the Plover River, a tributary of the Wisconsin River.

METHODS

All ponds were mapped to determine surface areas and volumes. Mean depths were calculated by dividing volume by surface area. During mapping, bottom sediments were characterized as muck, marl, sand, or gravel and beds of aquatic vegetation were delineated and species composition noted. Sediment cores were taken from Krause and Sunshine Springs before dredging. A 5-meter length of irrigation pipe (I.D. = 15 cm) was pushed into the sediments until mineral soil was reached. The pipe was then retracted and sediments were forced out with a plunger. Cores taken from Sunshine Springs were visually characterized with respect to depth as clay, marl, marl-organic mixture, and organic. Cores taken from Krause Springs were analyzed for percentage oxidizable organic matter and carbonates (Baxter 1970).

A hydrology study was conducted under contract by the U.S. Geological Survey to determine the influence of dredging on ground water tables and discharge of ponds. Study sites included Krause, Sunshine and Maxwell Springs, which served as a control. Methods and results of this study were reported by Rose (1977).

From 1968 to 1973, Taylor recording thermometers (Model No. 76J) were used to measure water temperatures at Krause, Sunshine and Maxwell Springs. Temperatures were measured 15 cm below the pond surface and on the bottom near the deepest parts of the ponds. Outlet temperatures were also monitored at Krause and Sunshine Springs. Vertical changes in water temperature and dissolved oxygen were measured from 4 to 6 times per year during the open water season and at irregular intervals during winter months.

Water samples were collected on a quarterly basis for one year before and one year after dredging at the study ponds and at Maxwell Springs. Samples were collected from pond surfaces and outlets and on several occasions samples were taken from flowing wells adjacent to the ponds. Analyses of water samples included: pH, total alkalinity, common forms of nitrogen and phosphorus, and most of the common anions and cations.

Benthic communities in the study ponds were sampled on 6 to 7 different dates per year for two years prior to dredging. A 15-centimeter Ekman dredge was used to collect samples from about 10 randomly chosen stations. After dredging, the sampling schedule was altered. About 24 samples were collected on three to four dates during the year each pond was dredged, on four dates the year after dredging, and in 1975, the final year of study. Samples were also collected in fall of the interim years. The benthic community in Maxwell Springs was sampled from 1969 to 1971 (Carline 1975).

Benthic samples were washed through a #30 mesh screen bucket and preserved in 5 percent formalin. In the laboratory, samples were sorted into major taxa and transferred to 70 percent methanol. After further sorting, organisms were blotted, allowed to air dry for 5 minutes and weighed. Some samples remained in methanol for periods up to 320 days before weighing. Because wet weights of preserved invertebrates will decrease with time, an experiment was conducted to determine loss of wet weight by major invertebrate groups (Carline 1975). Results of this experiment yielded appropriate correction factors to determine live weights of benthic organisms.

Zooplankton was usually sampled in Krause and Sunshine Springs when benthos was collected. Before dredging we attempted to quantify zooplankton by straining 15 liters of water through a #20 mesh plankton net. Too few animals were collected in this manner to permit quantification, hence, we towed the plankton net through the open water to obtain qualitative samples. After dredging when zooplankton increased, it was possible to estimate their densities. Samples were taken from one or two sites at each pond, near areas of maximum depth. Each sample consisted of two vertical tows. The plankton net was slowly lowered to within 10 cm of the bottom and then raised to the surface. The procedure was then repeated. We assumed net efficiency was 100 percent when calculating volume of water strained. Because actual net efficiency was probably 80-90 percent, zooplankton densities were underestimated.

We estimated densities of trout populations using the Petersen mark and recapture method. Nearly all samples of fish were collected with a 230-volt ac boom shocker. On several occasions we tried seining and trap netting; however, electrofishing was the most efficient method of capture. Most electrofishing was conducted at night. Trout were held overnight in screen cages and processed the following morning. All fish collected on the first run were anesthetized with methyl pentynol, measured to the nearest 2.5 mm, and given a partial finclip. About 25 fish in each 25-mm length interval were weighed to the nearest gram. After processing, trout were held for about 30 minutes to check for handling mortality and then released. A second electrofishing run was usually made two to three nights later.

Age structures of trout populations were determined from length distributions of known-age fish and scale analyses. Fall fingerlings and spring yearlings, determined from length frequency distributions, were permanently marked by fin removal. Estimated numbers of trout in each 25 mm length group were placed in appropriate age groups based on relative proportions of known-age fish. The electrofishing gear was size selective. Efficiency was lowest for smallest fish and increased until fish size reached about 12 cm. By estimating numbers of fish within relatively small length intervals, changes in gear efficiency were accounted for.

Trout biomass was estimated by multiplying mean weight of individual fish in a length interval or age group by estimated density. Biomasses at the beginning and end of a sampling interval were averaged to calculate mean biomass (B). Instantaneous growth rates (G) and total mortality (Z) were calculated following Ricker (1975).

We sampled a portion of Elton Creek and the entire length of Krause outlet (153 m) to obtain data on growth of trout in outlet waters and on movement of trout between ponds and adjoining streams. In May 1968 and each fall from 1968 to 1971 we made single-run, electrofishing surveys in a 1-km section of Elton Creek (Fig. 1). Outlets of Clubhouse and Sunshine Springs entered Elton Creek at the approximate midpoint of a sample section. We made population estimates of brook trout in Krause outlet every fall from 1967 to 1975 and we also made some midsummer population estimates. In both Elton Creek and Krause outlet, fingerlings were permanently marked so that they could be distinguished from fingerlings captured in adjacent ponds.

Each fall we surveyed the shorelines of Krause and Sunshine Springs to determine locations and numbers of brook trout redds. All reference ponds were surveyed at least once. We sampled a total of 52 redds in five spring ponds to determine embryo survival. Redds were excavated from early December through late February and trout embryos were separated from substrates by washing. Numbers of live and dead embryos were counted to estimate survival.

We conducted creel surveys on the study ponds and on several reference ponds during the entire fishing seasons of 1969, 1970, 1971, and 1975. Surveys were run 5 days per week. Census clerks worked 8 hours per day and work days started at 6:00 a.m. or 1:00 p.m. Fishing pressure was estimated from instantaneous counts of anglers at 2-hour intervals (Lambou 1961). Catch rates were estimated from data collected during interviews of anglers. Trout harvest was estimated monthly from the product of mean number of trout caught per hour and total number of angling hours. Along with the regular contact-type survey in 1969, we employed a postal survey to obtain additional harvest data. Results from the postal survey were biased and were not used to estimate any fishery statistics. Additional details of the creel census and postal survey are given by Carline (1972).

RESULTS

PRE- AND POSTDREDGING COMPARISONS

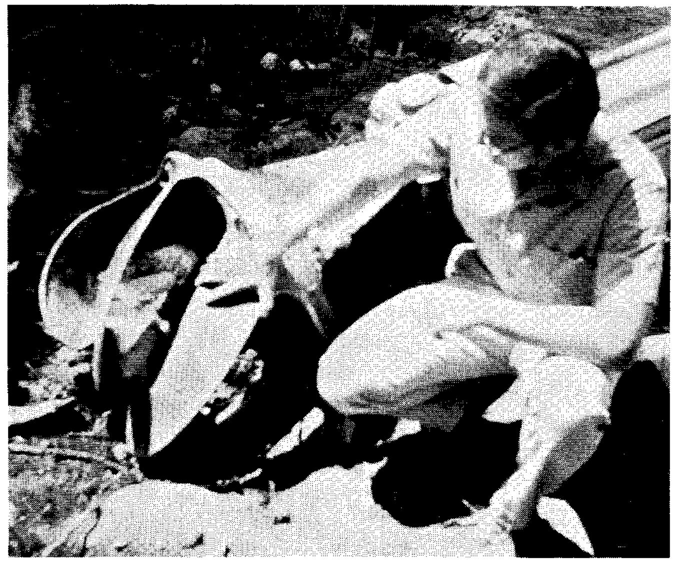
Physical Changes

The entire basins of Krause and Sunshine Springs were dredged to maximum depths of 3.7 m or until mineral soils were encountered. Removal of saturated soils along the shore resulted in increased surface areas, 17 percent at Krause Springs, and 8 percent at Sunshine Springs. The only littoral areas left in the ponds were sand-gravel bars. Parts of shorelines had steep gradients after dredging and in some instances shorelines were undercut. Numerous logs were removed from ponds to allow lateral movement of the intake pipe, yet after dredging many logs remained in the ponds. These logs plus submerged debris that protruded from shorelines provided ample cover for trout.

Before dredging, about 60 percent of Krause Springs was less than 0.5 m deep and maximum depth was 1.1 m (Fig. 2). Dredging increased pond volume by more than 500 percent. Mean depth was increased by fivefold and maximum depth was increased to 3.7 m (Table 2). Physical changes at Sunshine Springs were similar; volume was increased by

The DNR owns two dredges such as this one. It is equipped with a 6-inch intake pipe and powered by a 140 hp engine.

The disposal line, leading from the dredge, is supported by a series of floats.



The dredge cutterhead spins rapidly, and breaks up sediments, and a slurry is pumped through the pipeline to the disposal site.

fourfold and mean and maximum depths were more than tripled (Fig. 3).

Before Krause Springs was dredged, sediments at the mud-water interface were rather uniform in color and consistency over most of the pond. There was only 1 m² of sand and gravel in the entire pond. Predominant sediments were dark brown in color and formed a flocculent suspension. These sediments were composed of 50 to 77 percent organic matter (Baxter 1970). Depth of sediments ranged from less than 1 m to 6 m deep. Baxter (1970) took cores of sediments and found that the percentage of organic matter tended to be highest near the top of the cores, while proportions of carbonates (mostly marl) were greatest near the bottom of the cores. Below the marl layer there was a narrow stratum of silt and clay overlying mineral soils. After the pond was dredged there was a substantial increase in areas of exposed gravel; these substrates totaled 6 percent of the pond bottom. Remainder of the bottom consisted of dark-colored sediments. We did not analyze sediments after dredging, but based on Baxter's (1970) findings, we suspect that carbonates made up a major portion of the sediments.

Before Sunshine Springs was dredged, sediments were more heterogeneous than at Krause Springs. There was a narrow strip of gravel along the north shore that comprised less than 5 percent of the pond bottom. About 60 percent of the bottom was covered by a dense bed of *Chara vulgaris*. Sediments varied considerably in color and consistency. Some were tan in color and formed a loose suspension; these appeared to consist of partly decomposed plant material and marl. In other parts of the pond there were areas of nearly pure white marl and in the deepest areas of the pond, sediments were

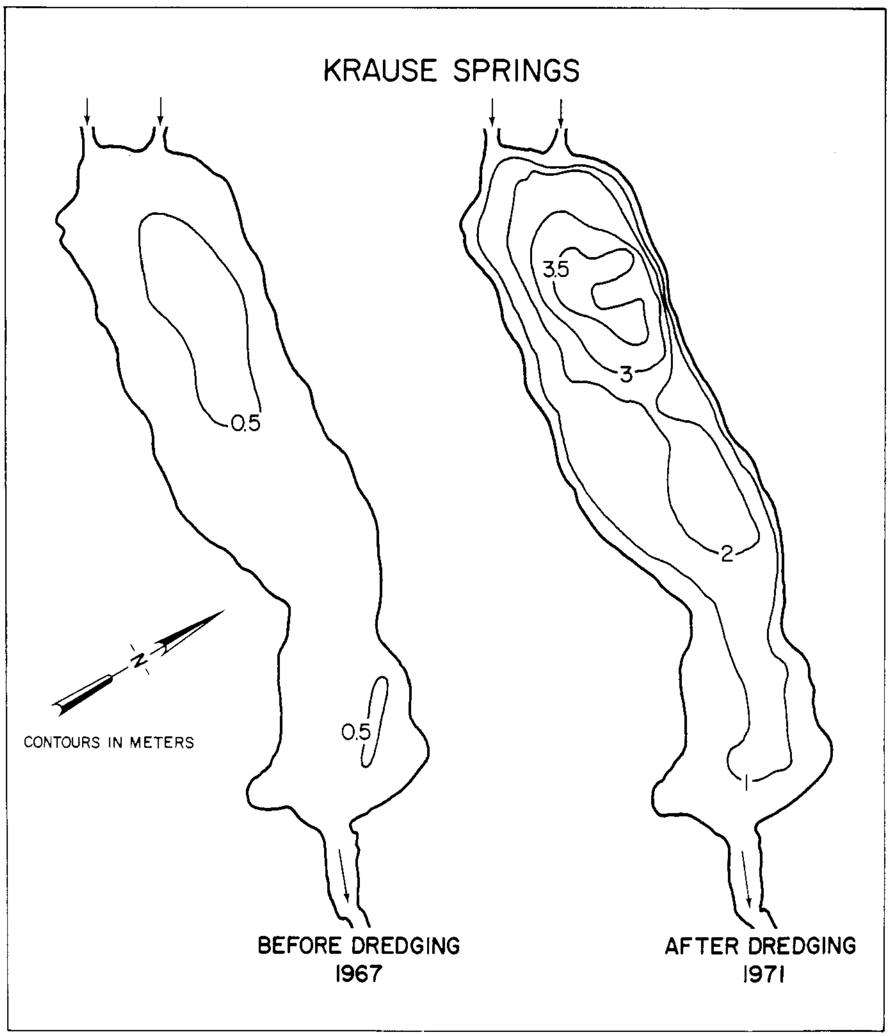


FIGURE 2. *Hydrographic maps of Krause Springs before and after dredging.*

dark brown and flocculent. Vertical composition of sediments varied greatly. Some cores were marl from the top to bottom while others showed some gradation from highly organic materials at the top of the cores to mostly marl at the bottom. Beneath the organic and marl sediments there was a layer of silt and clay overlying mineral soils. After dredging, bottom materials were primarily marl and color varied from light to dark gray. Areas of exposed sand and gravel did not change appreciably except for a developed spawning area along the northwest shore.

Changes in flow of ground water entering dredged ponds appeared to be related to: (1) locations of major ground water emergence, (2) areas of clay layers overlying mineral soils, and (3) the extent to which these clay layers were disrupted by dredging. The increase in discharge at Sunshine Springs was due to both dredging and increased annual precipitation. Rose (1977) accounted for changes in precipitation and calculated that increased flow due to dredging alone, was 41 percent. He felt that the clay layer was effectively disrupted during dredging and that the hydraulic connection between the pond and underflow of ground water was improved. At Krause Springs most of the clay layer was beyond the reach of the dredge intake; hence, this layer was not affected by dredging and inflow of ground water was unchanged (Rose 1977).

Ground water supplied 99 percent of total flow to the study ponds (Rose 1977), hence chemical characteristics of pond waters were similar to those of ground water. We compared concentrations of dissolved materials in outlet waters and from flowing wells at Krause and Sunshine Springs (Tables 3 and 4). Nitrates and dissolved phosphorus were higher in well water than in the ponds and nitrites and organic nitrogen were higher in the pond waters than in wells. Differences were probably due to uptake of nutrients by primary producers and conversion of inorganic nitrogen to organic forms.

There was little change in chemical characteristics of pond waters as a result of dredging. At Sunshine Springs nitrates increased and organic nitrogen decreased after dredging (Table 4). At Krause Springs all forms of nitrogen increased slightly after dredging, but differences were small (Table 3). Magnesium concentrations appeared to increase after dredging in both ponds. Rose (1977) examined many of the same parameters that we did, but he sampled outlets the first and second years after dredging. He found no appreciable effect of dredging on chemical characteristics of pond waters.

Thermal and oxygen conditions in both study ponds were similar before and after dredging. Therefore, we will show only data from Sunshine Springs to illustrate pre- and post-dredging conditions.

Rapid turnover of water in Sunshine Springs (32 hr) before dredging allowed formation of only a thin layer of ice (2 to 8 cm) during winter months and water temperatures at the bottom ranged from 6 to 7°C, depending on where ground water emerged (Fig. 4). In both winter and summer months, concentrations of dissolved oxygen always remained above 6 mg/l, because of high concentrations of dissolved oxygen in the ground water (7-9 mg/l). During summer months water temperatures at the surface approached 20°C, but declined rapidly with depth. It was common to find 8 to 10°C decreases in temperature within the upper 0.5 m. After Sunshine Springs was dredged, the exchange time increased from 32 to 92 hr, however, this increased residence time had no apparent effect on temperature profiles during summer or winter months. Surface and bottom temperatures and concentrations of dissolved oxygen were similar before and after dredging.

A major consequence of dredging was the provision of increased volume of water with moderate temperatures. Before dredging, there was only a narrow

TABLE 2. *Physical characteristics of study ponds before and after dredging.*

Pond and Period	Surface Area (ha)	Volume (m^3)	Mean Depth (m)	Maximum Depth (m)	Mean Annual Discharge (m^3/sec.)*
Krause Springs					
Before	0.30	987	0.34	1.07	0.014
After	0.36	5,923	1.68	3.66	0.014
Sunshine Springs					
Before	0.36	1,725	0.46	1.22	0.014
After	0.38	6,910	1.68	3.66	0.020

*Rose (1977)

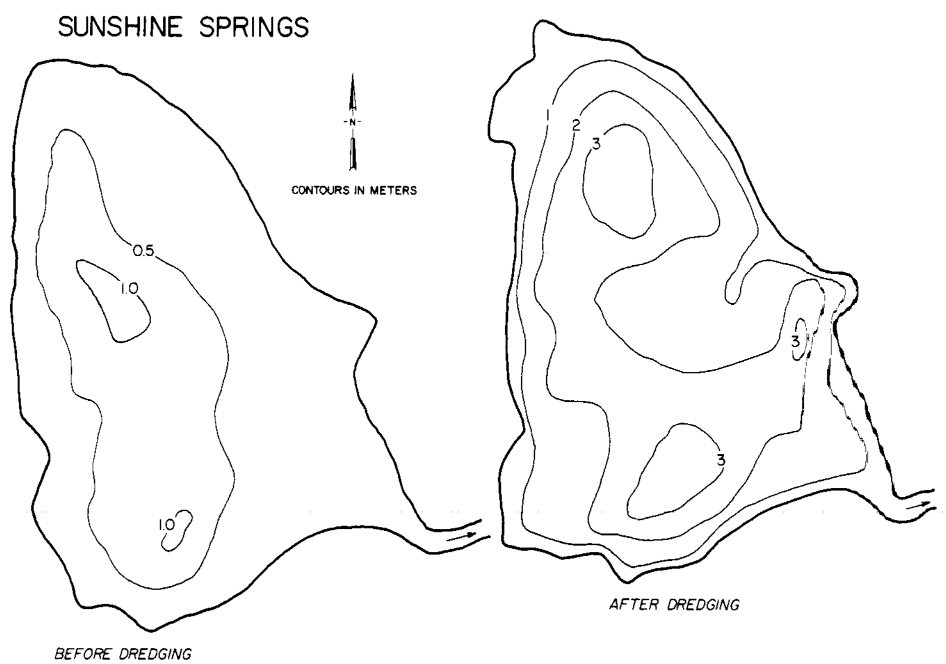


FIGURE 3. *Hydrographic maps of Sunshine Springs before and after dredging.*

TABLE 3. *Chemical characteristics of Krause outlet before and after dredging and of a flowing well adjacent to the pond.*

	Predredging				Postdredging				Flowing Well
Parameter	21 Jul 1969	21 Oct 1969	26 Jan 1970	20 Apr 1970	20 Jan 1975	29 Apr 1975	25 Jul 1975	8 Oct 1975	20 Jan 1975
pH	8.0	7.6	7.8	–	8.0	8.0	8.1	8.3	8.1
Total alkalinity (mg/l as $CaCO_3$)	178	164	171	–	162	170	–	–	155
Nitrite (mg/l-N)	0.004	*	0.002	*	0.009	*	0.008	0.012	*
Nitrate (mg/l-N)	0.8	0.9	1.0	0.6	1.1	0.7	0.6	1.49	1.7
Ammonia (mg/l-N)	**	**	0	0	0.04	0.07	0.02	0.05	**
Kjeldahl nitrogen (mg/l-N)	0.30	0.20	0.41	0.42	0.07	0.59	0.41	5.13	**
Dissolved phosphate (mg/l)	***	0.08	0.04	***	0.015	0.005	***	0.021	0.065
Total phosphate (mg/l)	0.1	0.2	0.2	0.1	0.02	0.06	0.06	0.04	0.04
Sulfate (mg/l)	12	12	12	14	9	15	8	8	5
Chloride (mg/l)	1	2	2	4	3	2	11	3	2
Calcium (mg/l)	–	43	–	–	–	–	–	–	–
Magnesium (mg/l)	20	18	17	18	25	–	25	26	26
Sodium (mg/l)	2	2	3	2	2	1	4	4	3
Potassium (mg/l)	0.9	1.4	1.3	1.0	2.9	2.7	1.1	1.6	2.6
Specific conductance (μmhos/cm at 25°C)	–	–	–	–	318	239	273	225	309

*less than 0.002
**less than 0.03
***less than 0.005

TABLE 4. *Chemical characteristics of Sunshine outlet before and after dredging and of a flowing well adjacent to the pond.*

	Predredging				Postdredging				Flowing Well
Parameter	21 Jul 1969	21 Oct 1969	27 Jan 1970	20 Apr 1970	20 Jan 1975	29 Apr 1975	25 Jul 1975	8 Oct 1975	20 Jan 1975
pH	8.0	7.7	7.7	–	7.9	8.1	7.9	8.2	8.0
Total alkalinity (as mg/l $CaCO_3$)	172	183	178	–	–	177	150	–	167
Nitrite (mg/l-N)	0.018	0.002	0.010	*	0.009	0.011	0.003	0.006	0.009
Nitrate (mg/l-N)	0.4	0.2	0.3	0.1	0.5	0.4	0.2	0.6	0.7
Ammonia (mg/l-N)	**	0	0.04	0	**	0.10	**	**	0.05
Kjeldahl nitrogen (mg/l-N)	0.21	0.24	0.31	0.24	**	0.14	0.33	**	**
Dissolved phosphate (mg/l)	**	**	0	**	0.025	0.026	****	****	0.006
Total phosphate (mg/l)	***	0.1	0.1	0.1	0.02	0.02	0.02	0.02	0.01
Sulfate (mg/l)	12	12	12	12	9	10	6	6	8
Chloride (mg/l)	1	2	1	5	2	2	7	2	2
Calcium (mg/l)	40	–	–	–	–	–	40	–	–
Magnesium (mg/l)	20	18	17	19	24	–	25	25	25
Sodium (mg/l)	2	2	2	2	3	1	3	4	2
Potassium (mg/l)	1.4	1.2	1.1	1.4	3.6	8.1	1.1	2.1	3.0
Specific conductance (μmhos/cm at 25°C)	–	–	–	–	331	332	285	204	318

*less than 0.002
**less than 0.03
***less than 0.1
****less than 0.05

stratum of water above 10°C during May to September (Fig. 5). After dredging this stratum of water above 10°C more than doubled. Similarly, during winter months there was an increased volume of water above 4°C. Thus, dredging created an increase in volume of water with temperatures conducive to high growth rates of trout.

The only difference in effects of dredging on thermal conditions between Krause and Sunshine Springs was that outlet temperatures at Sunshine Springs changed while those at Krause Springs did not. Between May and September, outlet temperatures at Sunshine Springs decreased after dredging (Fig. 6). Part of this difference was due to cooler air temperatures after development. To account for annual differences in air temperature, the monthly means for outlet and air temperatures were plotted (Fig. 7). It was apparent that at a given air temperature, outlet temperatures after dredging were cooler in summer and warmer in winter. Changes in outlet temperatures were most influenced by increased discharge at Sunshine Springs. During the 2.5 year period after dredging, discharge was 55 percent greater than during the predredging interval (Rose 1977). Precipitation accounted for 14 percent of the increase and ground water flow accounted for 41 percent of the increase.

We suspect that changes in outlet temperatures accompanying increased flow were caused by a reduction in contact time between surface waters of the pond and the atmosphere. Outlet waters originate from the pond surface. This upper stratum absorbs most of the solar radiation in summer and is the area of greatest heat loss during winter. Increased flow should reduce the time of solar heating in summer and in winter reduced contact time with ice cover should result in less heat loss.

Aquatic Vegetation

Prior to development, Sunshine Springs supported dense stands of *Chara*. Plant biomass appeared lowest after ice-out and continually increased throughout the summer. By August the plants reached the water surface in much of the pond. The only open areas were those along shore, beds of marl, and the two small holes, each of which was about 1 m deep. In August 1969, *Chara* beds covered nearly 60 percent of the pond bottom. Dredging eliminated all plants and recolonization first became evident in mid-1971, about one year after dredging. By late 1975 most of the pond that was less than 2 m in depth supported some *Chara*. Isolated specimens of *Ranunculus* spp. were also found. In 1975, using aerial photographs we estimated that 28 percent of the pond supported *Chara*.

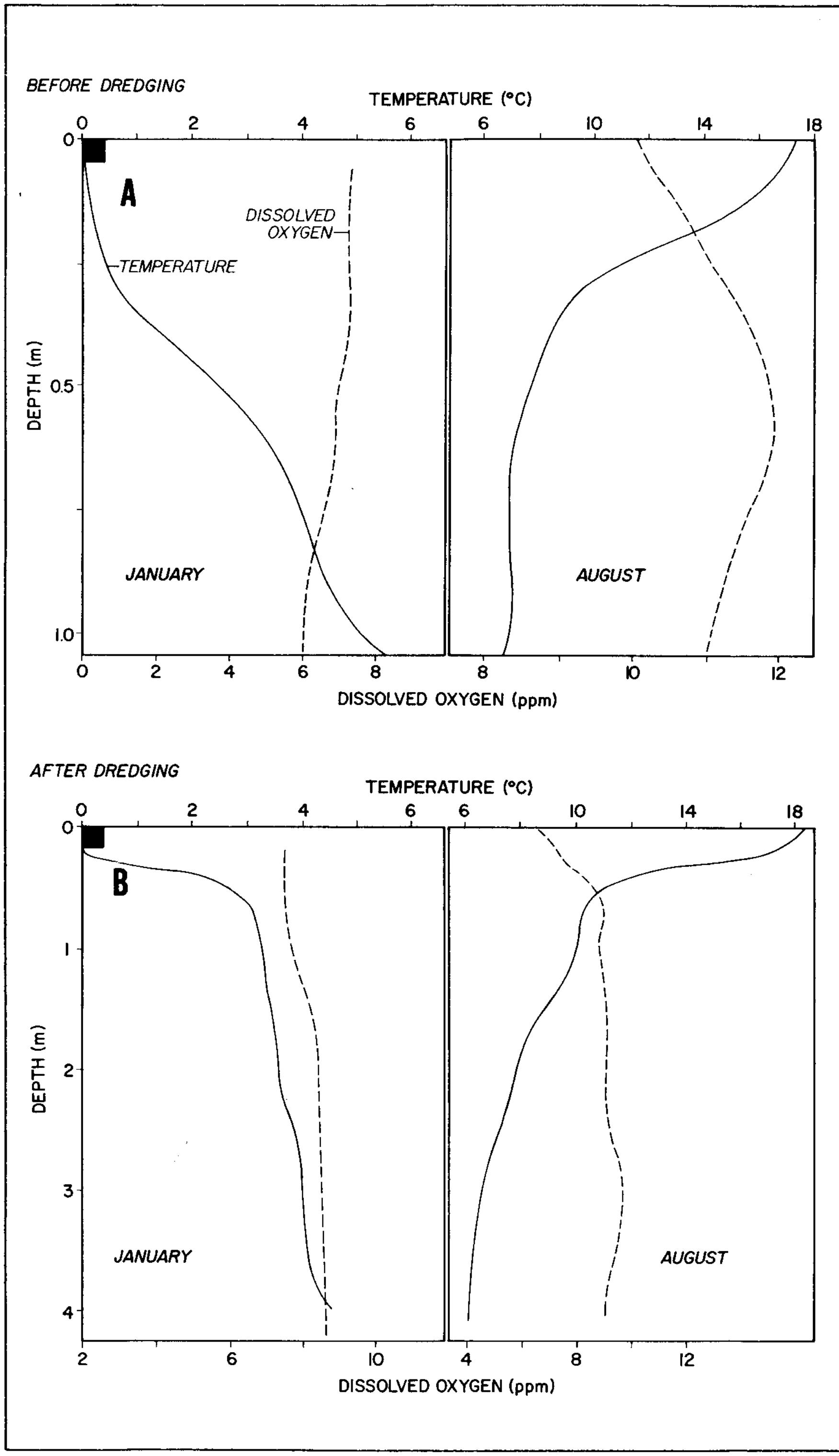


FIGURE 4. *Vertical changes in water temperature and concentrations of dissolved oxygen in Sunshine Springs before (A) and after (B) dredging. Pond was ice-covered in January.*

Weights of *Chara* collected during benthos sampling provide an index of mean biomass, because sample sites were chosen randomly on each collection date. In 1969-70, prior to dredging, mean wet weights of *Chara* ranged from 391 to 1,985 g/m² (Table 5). Plant biomass fell to zero immediately after dredging in 1970 and gradually increased over the following four years. Mean biomass of *Chara* in 1969 was 1,226 g/m² and in 1975, five years after dredging, the mean was 116 g/m², or about 10 percent of predredging levels.

Wet weights of *Chara* are misleading, because large amounts of calcium

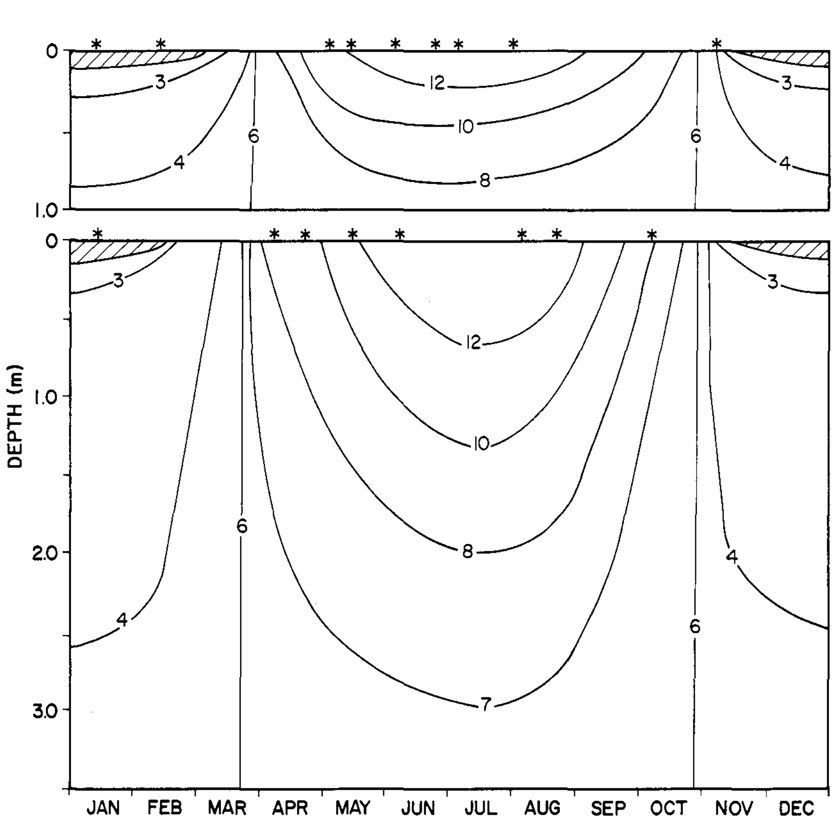


FIGURE 5. *Seasonal changes in water temperature (°C) with respect to depth in Sunshine Springs before (upper panel) and after (lower panel) dredging. Temperatures determined from vertical measurements (dates indicated by *) and from continuous recording thermometers. Hatched areas indicate ice-cover.*

In shallow ponds, aquatic plants grow to the surface, collect mats of filamentous algae, and make fishing impossible.

carbonate are precipitated on the plants. The following analyses of *Chara* samples collected from Clubhouse and Sunshine Springs in May 1973 provide correction factors to determine dry weights and proportions of combustible organic matter:

Dry:Wet Weight	20.2%
Composition of dried plants	
Combustible organic matter	38.1%
Calcium carbonate	54.3%
Other minerals	7.6%

Krause Springs supported a sparse population of *Anacharis canadensis* before dredging and biomass never exceeded 1 g/m², wet weight. After the pond was dredged, *Anacharis* recolonized slowly and by October 1975 mean biomass was 7 g/m². All of these plants occurred in the extreme east end of the pond where water depths were 1 m or less. We anticipate further increases in *Anacharis*, because in other ponds with similar depths and bottom types, biomass of *Anacharis* frequently exceeds 500 g/m².

Benthos

One of the most dramatic effects of dredging on the ecology of spring ponds was on the benthos. Because entire pond basins were dredged, benthic communities were virtually eliminated. Recolonization commenced soon after development, although recovery rates varied greatly among taxa. By 1975, structures of the benthic communities were considerably different than prior to dredging.

Changes in total density of benthic organisms following dredging were similar in both study ponds. In Krause Springs mean density of benthos was about 4,100 organisms/m² in 1968-69 (Fig. 8). In August 1971, immediately after dredging was completed, mean density was only 42 organisms/m² (Append. I). Recolonization was rapid and by late 1975 mean densities were nearly 10,000/m². At Sunshine Springs mean annual densities in 1968-69 were about 5,500 organisms/m² and soon after dredging in late 1970, densities had declined to 84/m² (Fig. 9). Invertebrates then increased steadily and by 1975 numbered about 16,000/m² (Append. II). In both ponds spatial distribution of invertebrates was "patchy", hence sample variances were large and confidence limits were correspondingly wide (Figs. 8 and 9).

Dredging resulted in changes in dominant invertebrate groups. Prior to development, chironomid larvae were the dominant group and in 1975 oligochaetes, primarily Tubificidae, were the most numerous animals in both ponds (Table 6). The importance of amphipods and leeches in the benthos diminished after dredging. Mean density of all taxa in Krause Springs was about 50 percent higher in 1975 than in 1969, while in Sunshine Springs, densities in 1975 were nearly three times as great as predredging densities (Table 6). Oligochaetes accounted for most of this increase at both sites.

Most invertebrate taxa had not reached predredging levels by 1975. At Sunshine Springs, leeches increased to 25 percent of predredging densities in 1975 and to only 2 percent of predredging densities in Krause Springs (Table 7). *Gammarus fasciatus* made notable gains in Sunshine Springs, yet attained only 30 percent of predevelopment levels in Krause Springs. *Hyalella azteca* was an important component of the benthos in Krause Springs in 1968-69 when mean densities were $91/m^2$. Dredging reduced the *Hyallela* population to less than $1/m^2$, and it has not increased since then. The density of chironomids was reduced by 61 and 46 percent after dredging in Krause and Sunshine Springs, respectively.

Reasons for the different responses of invertebrate populations to dredging are not clear. Reduced densities of chironomid larvae in Sunshine Springs may have been due to elimination of *Chara*, because several genera, particularly *Dicrotendipes*, maintained high densities in *Chara* beds. In Krause Springs there was little vegetation prior to dredging, so that failure of chironomids to reach predredging densities cannot be attributed to lack of attachment sites. Besides reduced populations, there were some changes in generic composition of chironomids in both ponds. *Chironomus* and *Phaenopsectra* were the most common genera in Krause Springs before dredging. In 1975, Tanypodinae and *Phaenopsectra* were the most common taxa (Table 8). In Sunshine Springs, percentage of larvae represented by *Dicrotendipes* declined and that of *Tanytarsus* increased after dredging.

The response of *Gammarus* to dredging was puzzling. *Gammarus* densities tended to be highest in sandy substrates and in Krause Springs the amount of sand bottom was increased substantially after dredging. Based on changes in areas of sand bottom, we expected a large increase in the *Gammarus* population in Krause Springs and little change in Sunshine Springs; the opposite occurred (Table 7).

In Krause Springs, *Hyalella* densities were highest in soft, organic substrates. After the pond was dredged, bottom types were mostly marl and *Hyalella* did not subsequently increase. Leeches were also associated with organic sediments so that their low densities in 1975 were not

TABLE 5. *Approximate mean biomass (wet weight) of Chara in Sunshine Springs. Samples collected with an Ekman dredge.*

Date	g/m^2
March 18, 1969	891
May 15, 1969	1,597
June 30, 1969	607
August 4, 1969	1,528
October 7, 1969	749
November 10, 1969	1,985
April 28, 1970	742
June 4, 1970	391
DREDGING	
October 2, 1970	0
April 12, 1971	0
June 21, 1971	5
August 17, 1971	12
October 19, 1971	46
April 21, 1972	4
June 14, 1972	4
August 14, 1972	60
October 11, 1972	39
May 15, 1973	55
July 5, 1973	43
October 17, 1973	167
October 7, 1974	205
April 30, 1975	47
June 17, 1975	212
August 14, 1975	126
October 8, 1975	79

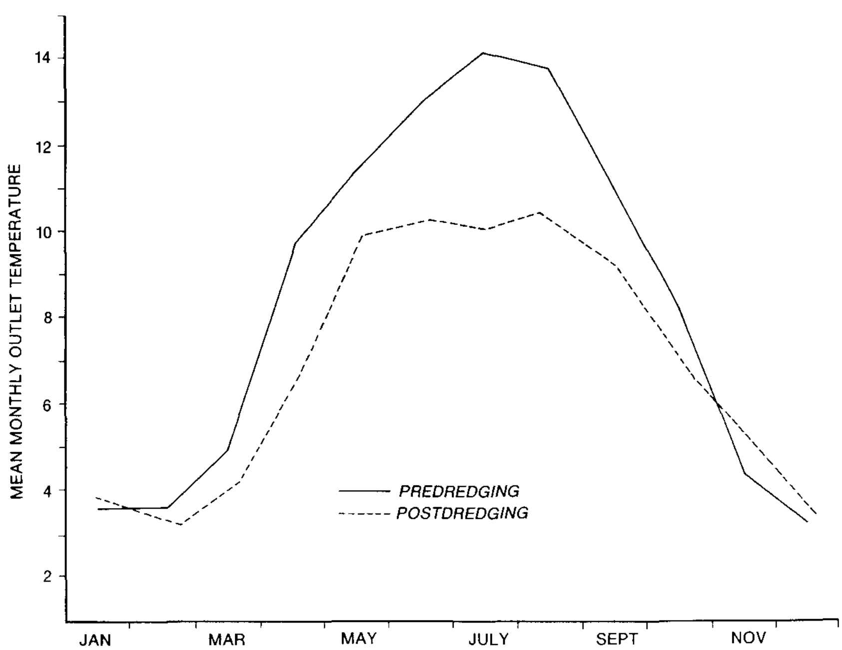


FIGURE 6. *Monthly mean water temperatures of Sunshine outlet prior to (1968-69) and following dredging (1970-72).*

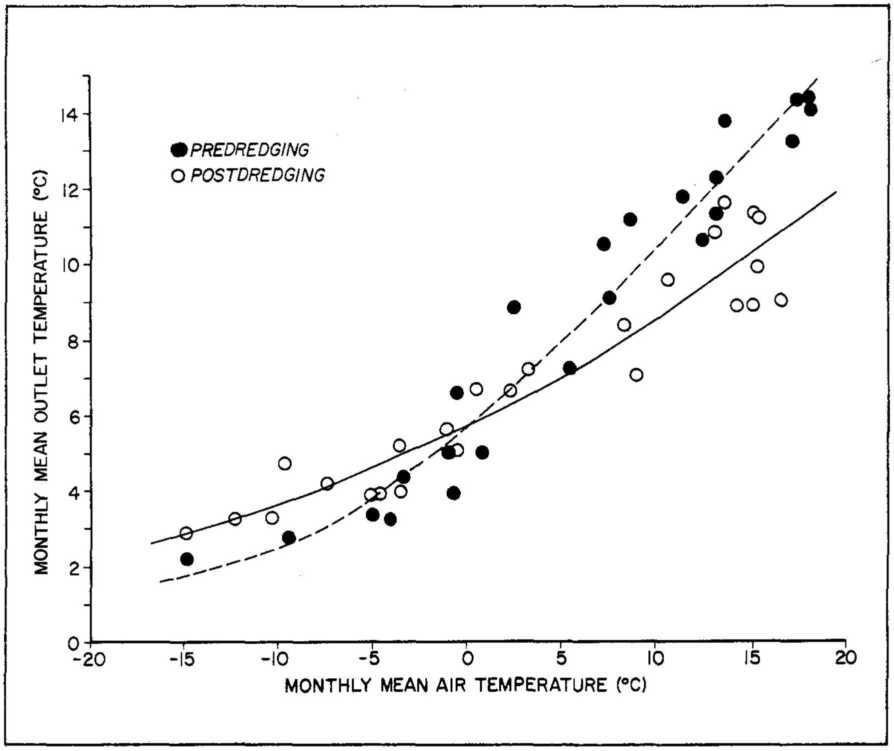


FIGURE 7. *Monthly mean outlet temperatures and air temperatures at Sunshine Springs before (1968-69) and after (1970-72) dredging. Lines were fitted by curvilinear regression.*

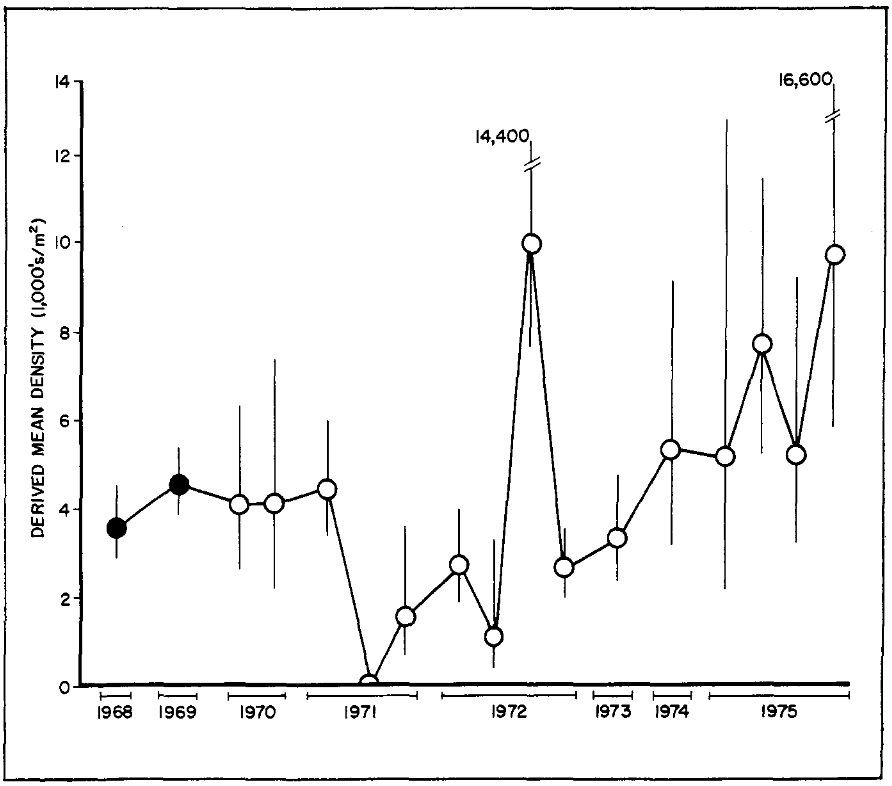


FIGURE 8. *Derived mean density of all benthic organisms in Krause Springs, 1968-75. Vertical lines represent 95% confidence limits. Solid circles represent annual means and open circles designate means for individual sampling dates.*

surprising. Failure of some invertebrate groups to increase after dredging cannot be attributed to trout predation, because trout populations in Krause Springs were similar before and after development.

The dramatic increase in tubificids, after dredging, was accompanied by changes in bottom types and reduced numbers of invertebrate predators. Tubificids frequently develop large populations in streams receiving domestic pollution or in profundal zones of lakes, situations where there are usually high levels of organic matter, concentrations of dissolved oxygen are often critical and few other organisms are present. In dredged ponds, substrates were predominately marl with little organic matter, hence changes in substrate types would not appear important in affecting tubificids. Dredging resulted in fewer invertebrate predators, including leeches and sialids. Chironomid larvae of the subfamily Tanypodinae have long been considered predaceous, but only recently Loden (1974) demonstrated that six different species of Chironominae preyed upon oligochaetes. He concluded that in a polluted stream, *Chironomus attenuatus* controlled densities of *Limnodrilus hoffmeisteri* through predation. If the Chironominae in dredged ponds were effective predators upon tubificids, the increase in tubificids following dredging may have simply been due to reduced predation. Combined densities of Tanypodinae and Chironominae in Krause Springs in 1975 were 66 percent below predredging levels while in Sunshine Springs densities were 53 percent lower than predredging densities.

It is likely that standing crops of benthic invertebrates in study ponds will continue to increase. As *Chara* beds further develop in Sunshine Springs invertebrate populations should do likewise. *Dicrotendipes* larvae, leeches, and trichopteran larvae attained highest densities in *Chara* beds. If *Anacharis* increases in Krause Springs, snail populations should develop, because *Anacharis* typically supports large numbers of them. Accumulation of organic matter in pond substrates from allocthonous sources and aquatic vegetation may also enhance benthic productivity of the predominately marl substrates. Leeches, *Hyalella*, and sialids were common in organic sediments. We cannot predict what levels benthic communities will attain, but suggest that in 1975 they were still in a transition phase.

Zooplankton

Prior to dredging, zooplankton densities in the open water of study ponds were too low to allow estimation. It is possible that densities among the vegetation, where we did not sample,

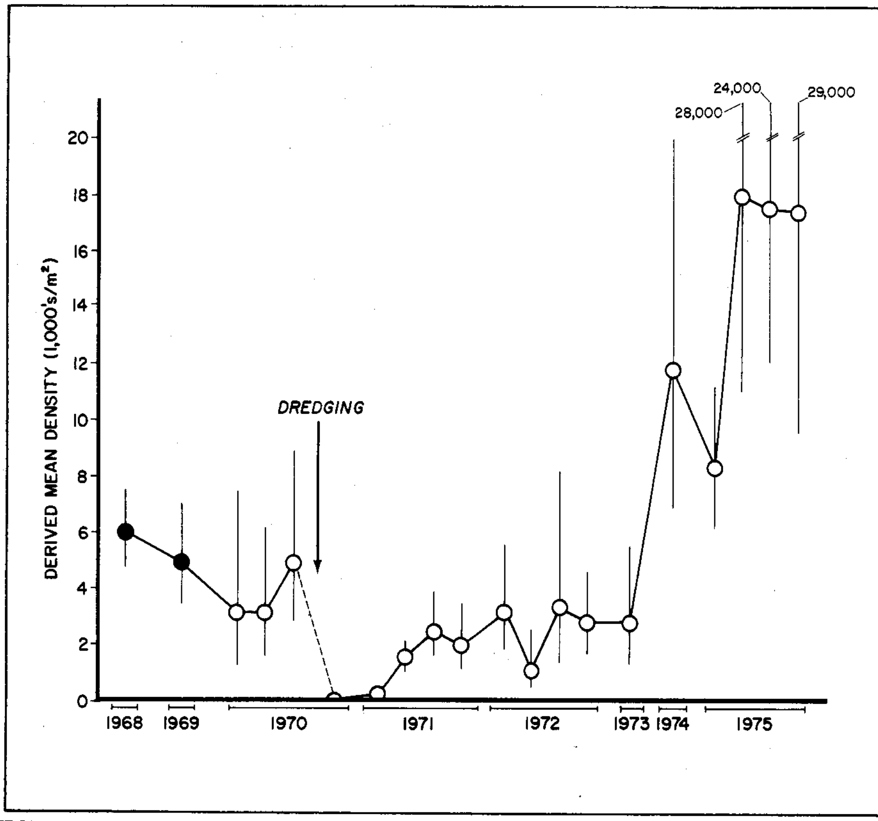


FIGURE 9. *Derived mean density of all benthic organisms in Sunshine Springs, 1968-75. Vertical lines represent 95% confidence limits, solid circles represent annual means and open circles represent means for individual sampling dates.*

TABLE 6. *Derived mean annual density and biomass of benthos in Krause and Sunshine Springs prior to dredging (1969) and six years afterward (1975). Representation of major taxa are given as percentages of total numbers and wet weights.*

	Krause Springs				Sunshine Springs			
	1969		1975		1969		1975	
No. of samples	73		96		68		96	
Derived mean (g/m^2)	34.4		28.1		25.0		60.9	
95% conf. limits	28.4; 41.6		22.5; 34.9		17.7; 34.9		48.8; 75.9	
Derived mean (no./m^2)	4,557		6,826		4,972		14,758	
95% conf. limits	3,864; 5,374		5,077; 9,176		3,541; 6,980		11,950; 18,225	
	Percent by:		Percent by:		Percent by:		Percent by:	
	Wt.	No.	Wt.	No.	Wt.	No.	Wt.	No.
Taxa								
Oligochaeta	1.1	4.2	56.7	70.1	2.2	4.0	47.8	56.0
Hirudinea	6.0	0.4	0.1	*	21.7	0.4	2.2	0.1
Pelecypoda	1.9	1.0	3.8	3.0	*	*	0.3	0.2
Gastropoda	1.0	0.1	0.4	0.2	7.0	0.8	1.8	0.3
Gammarus	18.4	6.0	12.1	5.0	13.9	3.2	30.7	10.2
Hyalella	29.4	38.0	0.4	*	*	*	0	0
Trichoptera	0.7	0.1	0.3	*	3.2	0.2	*	*
Chironomidae	40.7	49.8	23.1	20.6	51.8	91.2	15.9	31.8
Other Diptera	*	0.2	0.9	0.1	0	0.1	0.4	0.7
Sialidae	0.7	0.1	2.1	0.2	*	*	0	0
Miscellaneous	0.1	0.1	0.1	0.1	0.1	0.1	0.5	0.7

*less than 0.06

were higher than in open water. We were first able to quantify the zooplankton about one year after Krause Springs was dredged and about 1.5 years after development at Sunshine Springs. In both ponds, large populations of *Daphnia ambigua* and *Bosmina coregoni* and *longirostris* developed in 1972 (Tables 9 and 10). *Daphnia* densities declined in 1973 and remained at relatively low levels through 1975. *Bosmina* populations fluctuated greatly in 1973-75, but never attained the high levels of 1972.

We do not believe that the decline of *Daphnia* and *Bosmina* in 1973-75 was related to trout predation. Mean sizes of *Daphnia* ranged from 0.6 to 1.2 mm and they were eaten mostly by trout less than 150 mm in length. Mean sizes of *Bosmina* were usually less than 0.6 mm and their incidence in trout stomachs was always less than that of *Daphnia*. At least in Krause Springs, trout densities from 1972 to 1975 changed little, so that overgrazing of these cladocerans does not seem probable.

Utilization of *Daphnia* by trout appeared directly related to *Daphnia* densities. In 1972, incidence of *Daphnia* in trout stomachs was high, whereas in 1975 after *Daphnia* populations declined, their incidence in trout stomachs was low. It is possible that *Bosmina* were heavily utilized by trout less than 6 months of age, but we did not sample Age 0 trout until July. Although the zooplankton community positively responded to dredging, the effect of this food resource on adult trout did not appear significant.

Structure of Fish Community

Community structures in the study ponds and in many spring ponds we have surveyed were quite simple. In Krause and Sunshine Springs, the major portion of the total fish biomass was trout. It should be emphasized that these populations, brook trout in Krause Springs and both brook and brown trout in Sunshine Springs, were wild and were not influenced by stocking of hatchery fish. We did not attempt to estimate the density of other fish species. Before the ponds were dredged we estimated that the numerical density of fish other than trout was in the following order: the brook stickleback (*Culaea inconstans*), the mottled sculpin (*Cottus bairdi*), the common white sucker (*Catostomus commersoni*) and the mudminnow (*Umbra limi*). On occasion we found other species of fish in the study ponds, but these were considered transients and not part of the normal fauna.

Aside from the trout, dredging appeared to have the most effect on the stickleback. In Sunshine Springs, we found the density of this species highest in *Chara* beds. After dredging, *Chara* beds were sparse and few stickleback were

TABLE 7. *Comparisons of mean annual densities of major benthic taxa before and after dredging.*

	Krause Springs			Sunshine Springs		
	Means (No./m^2)		Ratio of Means	Means (No./m^2)		Ratio of Means
	1968-69	1975	1975/1968-69	1968-69	1975	1975/1968-69
Oligochaeta	54	2,460	46	53	3,503	66
Hirudinea	2.9	0.05	0.02	2.4	0.6	0.25
Gastropoda	1.0	0.6	0.6	5.2	2.0	0.39
Gammarus	46	14	0.30	6.2	68	11.0
Hyalella	91	0.1	0.001	2.0	0	–
Chironomidae	1,825	716	0.39	4,113	2,230	0.54

observed while electrofishing. We suspect that densities of mudminnows and sculpins were also affected by dredging, because they too were found among vegetation and were probably removed during dredging operations. It was apparent during the postdredging phase of the study that as *Chara* recolonized, densities of forage species increased. We concluded that dredging did not have any lasting effects on fish communities of the study ponds.

TABLE 8. *Percentage composition by genus and subfamily of Chironomidae larvae collected in Krause and Sunshine Springs before and after dredging.*

	Krause Springs		Sunshine Springs	
	1969	1975	1969	1975
Tanypodinae	12.4*	34.5	1.4	2.0
Chironomus	33.0	2.7	9.9	13.9
Phaenopsectra	37.5	37.0	3.6	3.4
Dicrotendipes	6.7	3.8	73.7	57.2
Tanytarsus	9.6	12.9	10.5	21.9
Prodiamesa	0.7	2.8	0.2	**
Orthocladinae	0	0	0.1	**
Others	0.1	6.3	0.6	1.5

*percent of total numbers collected
**less than 0.06

Trout Density and Biomass

Before the ponds were dredged, densities and biomass of trout populations were most affected by migrations. Rates of immigration and emigration were high in both ponds and populations could be best described as transient. We had difficulty in determining age structures of populations, because growth rates were quite variable and large numbers of scale samples were needed to determine ages of trout. Therefore, we have described responses of trout populations to dredging in terms of density and biomass of size groups rather than age groups. To make comparisons of trout populations before and after dredging we used data from 1974 and 1975, three to four years after dredging, to describe postdredging populations. Benthic organisms, the major food of trout, were markedly reduced by dredging. It took several years for the food supply to recover, so that we considered the first three years after dredging as a transition period.

Throughout the study there was great variation in trout density within and among years at Krause Springs (Table 11). Changes in trout density were due primarily to migrations. Predredging densities ranged from 109 to 2,547 trout/ha and fish less than 152 mm accounted for most of this variation. Range of trout density after dredging was also large, from 390 to 2,488 trout/ha. Because small fish were responsible for fluctuations in trout numbers, biomass changes were not as large as numerical ones. After dredging, population fluctuations decreased in magnitude. Before dredging the mean absolute change in trout density between successive estimates was 208 percent and after dredging it was 77 percent.

When data from 1974-75 were used to describe the postdredging population in Krause Springs, it appeared that increased pond volume had little influence on the trout population (Table 12). Mean density of trout in 1974-75 was 4 percent less than the predredging mean, and the mean biomass decreased by 2 percent after dredging. In this instance means may not be the most satisfactory measure of population response. Extreme variations in trout density were masked by mean values. The most significant impact of dredging on the trout was reducing their population fluctuations.

Fluctuations in trout density were most extreme at Sunshine Springs. Brook trout densities ranged from 25 to 3,962 trout/ha before dredging and from 363 to 3,094 trout/ha afterwards (Table 13). Densities of brown trout also fluctuated greatly (Table 14), though brown trout comprised only 3 percent of total trout numbers prior to dredging. The highest density of trout was found in April, 1968. There was a large movement of trout into the pond during the winter of 1967-68 when the population increased from 175 to 4,105 trout/ha. Within the following 5 months there was large movement out of the pond and density fell to 52 trout/ha in

TABLE 9. *Mean density of zooplankton throughout the water column, Krause Springs, 1969-75.*

Date	*Daphnia ambigua*	*Bosmina*	Cyclopidae	Chydoridae
30 Jun 1969	0	0	0	0
11 Oct 1969	0	0	0	0
9 Jun 1970	0	**	**	0
12 Apr 1971	0	0	**	0
25 Apr 1972	0	0	0.3	0
12 Jun 1972	0.5*	0.2	17.0	0
15 Aug 1972	49.3	55.7	18.3	0
23 Aug 1972	45.8	367.0	5.8	0
11 Oct 1972	51.0	182.0	2.3	0
26 Jan 1973	**	**	**	0
16 Apr 1973	**	**	0.1	0
22 Oct 1973	5.1	48.2	5.4	1.1
25 Jan 1974	0	0	**	**
7 Oct 1974	8.7	48.1	6.2	0
30 Apr 1975	0	0	0.6	0
17 Jun 1975	0	1.3	3.0	0
7 Oct 1975	**	62.1	9.5	0

*mean number/liter
**less than 0.05

TABLE 10. *Mean density of zooplankton throughout the water column, Sunshine Springs, 1969-75.*

Date	*Daphnia ambigua*	*Bosmina*	Cyclopidae	Chydoridae
30 Jun 1969	0	0	0	0
11 Oct 1969	0	0	0	0
9 Jun 1970	0	0	0	0
12 Apr 1971	0	0	0	0
21 Apr 1972	0.6*	0.3	0.3	0.3
14 Jun 1972	2.4	16.5	**	**
15 Aug 1972	13.0	145.0	0.6	0
11 Oct 1972	21.0	49.3	0	0
26 Jan 1973	12.6	0.1	0.2	0
16 Apr 1973	9.1	3.3	0.3	0
17 Oct 1973	0.2	2.0	0	0.1
25 Jan 1974	0	**	**	**
7 Oct 1974	1.0	78.5	0.1	0
30 Apr 1975	1.6	17.0	**	0
17 Jun 1975	5.9	26.1	0.1	0
7 Oct 1975	0.1	92.2	3.9	0.4

*mean number/liter
**less than 0.05

August 1968. Following dredging, changes in densities of trout were much less pronounced. The mean absolute change in trout density between successive estimates before dredging was 995 percent and in 1974-75 it was 95 percent.

Mean densities of brook trout in 1974-75 were 37 percent greater than predredging densities and biomass increased by 62 percent (Table 15). Brown trout in Sunshine Springs made the most notable increases after dredging; average postdredging densities increased from 44 to 151 trout/ha and mean biomass increased from 1.4 to 34.2 kg/ha. For both species combined, the increases in density and biomass were 37 and 152 percent, respectively. Prior to dredging, brown trout comprised 3.5 percent of total trout biomass and in 1975 brown trout accounted for 54.6 percent of the trout biomass. Therefore, the response of the trout population in Sunshine Springs to dredging was due mostly to the increase of brown trout.

Spawning and Fry Production

Brook trout began spawning in mid-October. Peak activity was in early November, although spawning continued well into December. The latest spawning act we observed was on January 9, at Maxwell Springs. Brasch (1949) also observed courtship activity in spring ponds in January.

Redds were constructed in sand and gravel substrates that had upwelling ground water. Substrate size did not appear to be important, provided it could be moved by digging females. Females usually constructed redds in gravel that was less than 25 mm in diameter. We found several redds in pure, but coarse sand. In most redds, eggs were deposited at depths of 7 to 15 cm.

The upwelling ground water with its relatively constant temperature (about 6°C) and high concentration of dissolved oxygen (about 8 mg/l) provided excellent incubation conditions for trout eggs. Unlike trout redds in streams, sedimentation was not a problem in spring ponds. In individual redds, survival of live embryos to eyed-egg or alevin stage ranged from 76 to 99 percent (mean = 89 percent). In areas of high redd density embryo survival was as low as 40 percent; we attributed low survival in these redds to disturbance of previously laid eggs by digging females—superimposition. Brasch (1949) trapped emerging fry from seven redds in several spring ponds and found a survival of 79 percent.

Before Krause Springs was dredged there was only 1 m^2 of sand suitable for spawning and it was not used every year. Most adult trout in Krause Springs spawned in the outlet as did many of the adult brook trout from Rabe Lake. Krause outlet provided most of the recruitment for both Krause Pond and Rabe Lake. As a result of dredging, about 40 m^2 of sand and gravel were exposed, but trout utilized only about half of this area for spawning (Table 16). In addition, we developed a spawning area of 75 m^2 along the northeast shoreline. As a result, numbers of trout spawning in the pond increased substantially.

We could not determine if increased spawning areas in Krause Springs affected year class strength, because fingerling trout migrated into the pond from the outlet throughout the summer. Prior to dredging, numbers of fall fingerlings ranged from 26 to 1,559/ha (mean = 420); nearly all were immigrants (Table 17). After dredging, numbers of fall fingerlings, which included pond residents plus immigrants, ranged from 168 to 1,744/ha (mean = 797). Differences in mean numbers of fingerlings before and after dredging were not significant (t-test; $P > 0.05$).

Before Sunshine Springs was dredged, there was a small spawning area of about 19 m^2 that accommodated about 22 female trout (Table 16). No new gravel areas were uncovered during the normal dredging operation; however, we developed a spawning area on the northwest shoreline that increased total area available for spawning to 75 m^2. We counted from 12 to 20 redds in the developed area and total redds in the pond ranged from 38 to 45.

We assumed that all fingerlings in Sunshine Springs had been hatched in the pond, because fingerlings marked in Elton Creek were not captured in Sunshine Springs until they were Age 1 or older. Numbers of fall fingerlings in Sunshine Springs increased after dredging (Table 17). Densities of fall fingerlings prior to dredging ranged from 20 to 898/ha (mean = 406). After dredging fingerling density ranged from 841 to 2,292 (mean = 1,370), and means were significantly different ($P < 0.05$). Therefore, dredging had a positive effect on year class strength in both ponds, but the increase was statistically significant only at Sunshine Springs.

TABLE 11. *Estimated density and biomass of brook trout in Krause Springs, 1967-75.*

Date	Trout Density (no./ha) Less than 152 mm	Greater than 152 mm	Total	Trout Biomass (kg/ha) Less than 152 mm	Greater than 152 mm	Total
15 Aug 1967	543	368	911	11.3	25.7	37.0
28 Mar 1968	2,119	428	2,547	32.6	25.9	58.5
12 Jun 1968	770	388	1,158	16.0	26.5	42.5
19 Aug 1968	632	398	1,030	8.7	25.3	34.0
15 Oct 1968	322	273	595	4.2	20.7	24.9
10 Apr 1969	30	79	109	0.8	7.5	8.3
21 Jul 1969	474	516	990	10.4	35.2	45.6
13 Oct 1969	293	539	832	6.2	33.7	39.9
8 Apr 1970	115	10	125	2.5	1.0	3.5
28 Jul 1970	569	381	950	13.0	20.6	33.6
29 Sep 1970	1,688	342	2,030	16.4	20.8	37.2
12 Apr 1971	484	441	925	7.5	24.3	31.8
DREDGING						
22 Sep 1971	483	59	542	6.4	2.4	8.8
26 Apr 1972	143	247	390	2.6	17.8	20.4
21 Jul 1972	2,042	446	2,488	15.0	28.1	43.1
29 Sep 1972	1,962	400	2,362	25.1	28.3	53.4
13 Apr 1973	914	106	1,020	13.1	10.5	23.6
5 Oct 1973	629	599	1,228	10.1	35.5	45.6
17 Apr 1974	454	441	895	7.8	27.8	35.6
7 Oct 1974	778	391	1,169	13.1	27.1	40.2
29 Apr 1975	604	323	927	11.0	22.6	33.6
23 Jul 1975	261	219	480	5.6	12.4	18.0
6 Oct 1975	1,146	340	1,486	12.2	21.1	33.3

Migration Patterns

Because migrations were a dominant feature of trout populations in study ponds, we have attempted to estimate numbers of trout that moved into and out of ponds between spring and fall population estimates. These calculations were made separately for fingerlings and for Age 1 and older trout. We first calculated survival rates of trout in Krause Springs that were permanently marked. Only postdredging data were used, because there was no evidence that trout were emigrating from the pond during that period. These survival rates were then used as a standard to determine if migrations had occurred. Too few permanently marked trout were captured in Sunshine Springs to calculate survival rates; we assumed survival in both ponds was similar.

If actual survival of trout fell within the appropriate range of survival rates found at Krause Springs (Table 18), we assumed no migrations had occurred. If survival was outside the appropriate range, we used mean daily mortality rates of permanently marked fish to calculate the expected number of trout at the end of the interval. The difference between expected and actual number of fish represented number of migrants.

Good spawning areas for brook trout can be easily recognized in winter as the high flow of groundwater keeps the area ice-free.

There was no seasonal pattern of migration at Krause Springs before dredging (Fig. 10). Large-scale movements into and out of the pond occurred both overwinter and oversummer. After the pond was dredged, there was no evidence of emigration, just immigration. From fall 1971 to fall 1975 the average

TABLE 12. *Summary of mean density and biomass of brook trout in Krause Springs before dredging and in 1974-75.*

	Predredging 1968-1970	Postdredging 1974-1975	Change Pre- vs. Postdredging
No./ha of trout:			
Less than 152 mm	701*	649	– 7%
Greater than 152 mm	335	343	+ 2%
Totals	1,036	992	– 4%
kg/ha of trout:			
Less than 152 mm	11.0	9.9	–10%
Greater than 152 mm	21.7	22.2	+ 2%
Totals	32.7	32.1	– 2%

*means

TABLE 13. *Estimated density and biomass of brook trout in Sunshine Springs, 1967-75.*

	Trout Density (no./ha)			Trout Biomass (kg/ha)		
Date	Less than 152 mm	Greater than 152 mm	Total	Less than 152 mm	Greater than 152 mm	Total
23 Aug 1967	42	133	175	0.4	12.2	12.6
27 Mar 1968	3,730	232	3,962	65.3	43.3	108.6
11 Jun 1968	696	440	1,136	17.4	24.1	41.5
22 Aug 1968	30	20	50	0.4	1.6	2.0
17 Oct 1968	146	111	257	2.8	5.5	8.3
7 Apr 1969	771	489	1,260	140	29.9	43.9
21 Jul 1969	15	10	25	0.2	0.8	1.0
15 Oct 1969	998	244	1,243	8.7	25.3	34.0
1 Apr 1970	341	200	541	4.8	10.4	15.2
DREDGING						
21 Oct 1970	832	311	1,143	44.7	32.3	77.0
27 Apr 1971	627	69	696	8.8	3.9	12.7
13 Jul 1971	566	7	573	8.5	0.6	9.1
13 Oct 1971	2,072	193	2,265	37.7	13.0	50.7
25 Apr 1972	257	106	363	5.2	6.5	11.7
21 Jul 1972	1,431	323	1,754	11.8	11.3	23.1
28 Sep 1972	1,358	183	1,541	12.6	14.7	27.3
13 Apr 1973	798	69	867	12.0	8.2	20.2
5 Oct 1973	1,388	842	2,230	18.6	76.6	95.2
15 Apr 1974	479	973	1,452	10.2	87.7	97.9
7 Oct 1974	1,190	657	1,847	16.6	41.4	58.0
29 Apr 1975	335	312	647	6.2	29.6	35.8
23 Jul 1975	409	310	719	8.5	23.9	32.4
6 Oct 1975	2,646	448	3,094	21.7	31.6	53.3

*less than 0.05

number of immigrants during each half-year interval was about 320 trout/ha. Most of the immigrants during overwinter periods were fall fingerlings and during oversummer intervals, spring yearlings were the most numerous.

Before Sunshine Springs was dredged there was a definite seasonal pattern of movement (Fig. 11). Brook trout moved into the pond overwinter and then emigrated during summer intervals. In March 1968 recent migrants accounted for 95 percent of the population and in April 1969 migrants made 88 percent of the population. After Sunshine Springs was dredged, there was only one of 10 sampling intervals in which a measurable number of trout appeared to emigrate. In 8 of 10 intervals there was movement into the pond. After dredging, mean numbers of brook trout immigrating oversummer was greater than numbers immigrating overwinter, 435 vs. 162/ha which was opposite of the migration pattern before dredging. Changes in migration patterns of brown trout were similar to that of brook trout.

During postdredging years at both sites, immigration rather than spawning in ponds contributed the major portion of total recruitment. At Krause Springs nearly 800 fingerlings were produced annually and at 33 percent overwinter survival, about 263 would be present as spring yearlings (Table 19). The average number of yearling and older trout immigrating into Krause Springs was 642/ha, so that total recruitment was 905 trout annually and spawning within the pond accounted for a maximum of 29 percent of annual recruitment. At Sunshine Springs fingerling brook trout accounted for 39 percent of total annual recruitment and brown trout accounted for 10 percent of the total. Thus, despite an increase in spawning areas in both ponds and larger year classes, immigration played an important role in maintaining trout populations. Had there been no immigration at Sunshine Springs, the response of trout populations to dredging may have been minimal. In this analysis, we have made several assumptions regarding survival rates. Even if we overestimated numbers of immigrants by 100 percent, we would still conclude that immigration played an important role in the recruitment process.

Food Habits

Brook trout in Krause Springs were sustained primarily by benthic invertebrates before and after dredging (Table 20). When food items were ranked by frequency of occurrence in trout stomachs, by number, or by weight, amphipods usually were the most important item, followed by immature chironomids. Prior to dredging, 61 to 95 percent of the amphipods in trout stomachs were *Hyalella; Gammarus* comprised the remainder. Dredging drastically reduced the *Hyalella* population and its density remained low during postdredging period. Only 2 percent of amphipods consumed by trout after dredging were *Hyalella*, while *Gammarus* became the most important food item. The brook stickleback was the primary forage fish and was consumed mostly by trout over 180 mm in total length. The frequency of occurrence and percentage by number of forage fish was low, but their contribution by weight was substantial. Other than the shift from *Hyalella* to *Gammarus*, food of the trout changed little as a result of dredging.

There were some differences in types of food eaten by trout of different lengths. During the postdredging phase, *Daphnia ambigua* was numerically the most important item for trout under 165 mm in length. Most of the cladocerans were *Daphnia*. Although *Bosmina* was considerably more numerous than *Daphnia*, *Bosmina* accounted for less than 5 percent of all cladocerans in trout stomachs. This differential rate of predation was probably due to relative sizes of prey. *Daphnia* averaged from 0.6 to 1.2 mm in length and nearly all *Bosmina* were less than 0.6 mm. Selection by fish of cladocerans greater than 1 mm has been well documented.

Analyses of the food of brook trout in Sunshine Springs was confined to trout over 150 mm in length, because few trout less than this length were taken before dredging. Prior to dredging the most important food items were: fish, amphipods, chironomids and leeches (Table 21). By weight, fish were the most important. Recovery of leeches after dredging was very slow and none were found in trout stomachs. Fish, amphipods, and chironomids were major food items after dredging; together they composed 93 percent by weight of all foods. Trichopterans, snails, and corixids increased in importance after dredging, but their contribution to trout diet was minor. With the exception of leeches, the same food organisms were important before and after dredging.

Growth

We were not able to compute growth rates for most age groups of trout prior to dredging because of large migrations and small numbers of permanently marked fish. There were only sufficient numbers of Age 1 trout in Krause Springs before and after development to compare growth rates and for this age group, the effect of dredging on growth was marked. Oversummer instantaneous growth rates

TABLE 14. *Estimated density and biomass of brown trout in Sunshine Springs, 1967-75.*

	Trout Density (no./ha)			Trout Biomass (kg/ha)		
Date	Less than 152 mm	Greater than 152 mm	Total	Less than 152 mm	Greater than 152 mm	Total
23 Aug 1967	0	0	0	0	0	0
27 Mar 1968	133	10	143	2.1	1.2	3.2
11 Jun 1968	109	2	111	2.6	0.3	2.9
22 Aug 1968	2	0	2	*	0	0
17 Oct 1968	0	0	0	0	0	0
7 Apr 1969	10	27	37	0.2	1.9	2.1
21 Jul 1969	0	0	0	0	0	0
15 Oct 1969	2	7	9	0.1	1.2	1.3
1 Apr 1970	5	0	5	0.1	0	0.1
DREDGING						
21 Oct 1970	5	20	25	*	2.1	2.1
27 Apr 1971	20	17	37	0.3	1.3	1.6
13 Jul 1971	7	0	7	*	0	0
13 Oct 1971	25	10	35	0.2	0.7	0.9
25 Apr 1972	5	15	20	*	3.1	3.1
21 Jul 1972	44	17	61	1.8	3.6	5.4
28 Sep 1972	44	57	101	0.4	4.1	4.5
13 Apr 1973	40	25	65	0.7	3.2	3.9
5 Oct 1973	12	130	150	*	21.3	21.3
15 Apr 1974	7	121	128	*	17.6	17.6
7 Oct 1974	5	195	200	*	43.8	43.8
29 Apr 1975	26	146	172	0.6	36.8	37.4
23 Jul 1975	10	99	109	0.4	35.2	35.6
6 Oct 1975	34	112	146	0.6	36.2	36.8

*less than 0.05

TABLE 15. *Summary of mean density and biomass of brook and brown trout in Sunshine Springs before dredging and in 1974-75.*

	Predredging 1968-1969	Postdredging 1974-1975	Change Pre- vs. Postdredging
Brook Trout			
no./ha			
Less than 152 mm	912	1,017	+ 12%
Greater than 152 mm	221	540	+144%
Totals	1,133	1,557	+ 37%
kg/ha			
Less than 152 mm	15.5	12.6	− 19%
Greater than 152 mm	18.6	42.8	+130%
Totals	34.1	55.4	+ 62%
Brown Trout			
no./ha			
Less than 152 mm	37	16	− 57%
Greater than 152 mm	7	135	+1,829%
Totals	44	151	+243%
kg/ha			
Less than 152 mm	0.7	0.3	− 57%
Greater than 152 mm	0.7	33.9	+4,743%
Totals	1.4	34.2	+2,343%
Both Species			
no./ha			
Less than 152 mm	949	1,033	+ 9%
Greater than 152 mm	228	675	+196%
Totals	1,177	1,608	+ 37%
kg/ha			
Less than 152 mm	16.2	12.9	− 26%
Greater than 152 mm	19.3	76.7	+297%
Totals	35.5	89.6	+152%

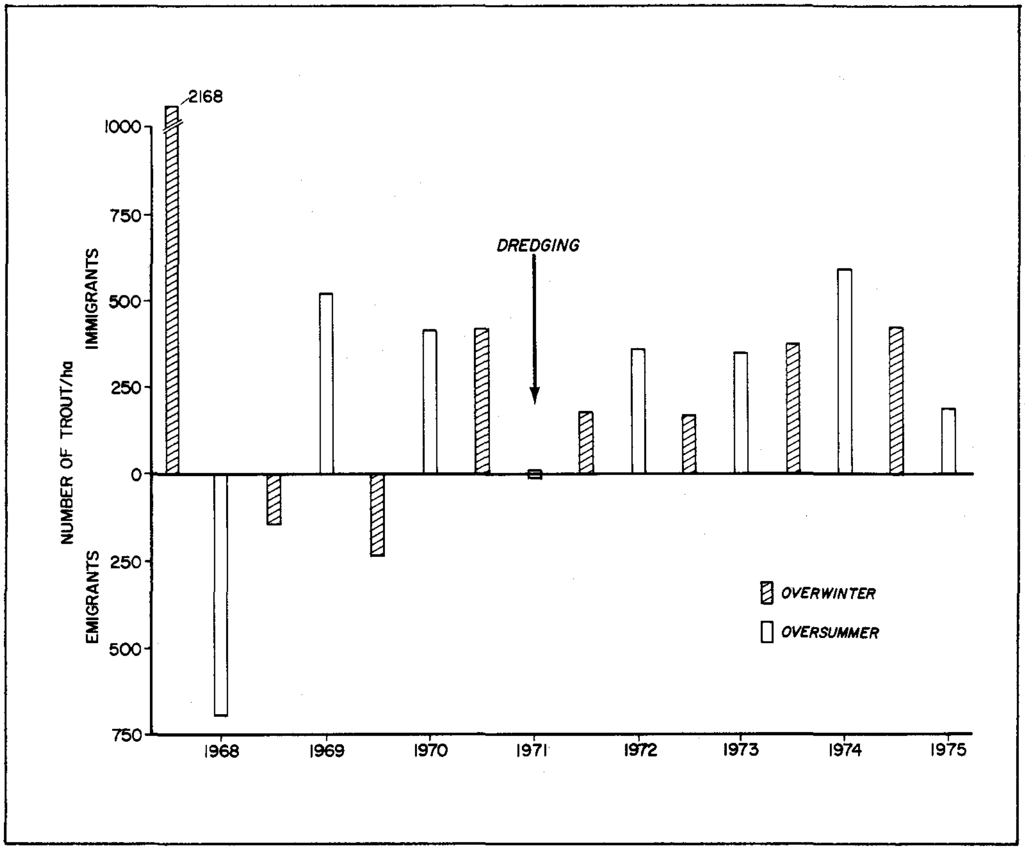


FIGURE 10. *Estimated numbers of brook trout that migrated into or out of Krause Springs, 1968-75. Overwinter periods are from October to the following April and oversummer periods are from April to October.*

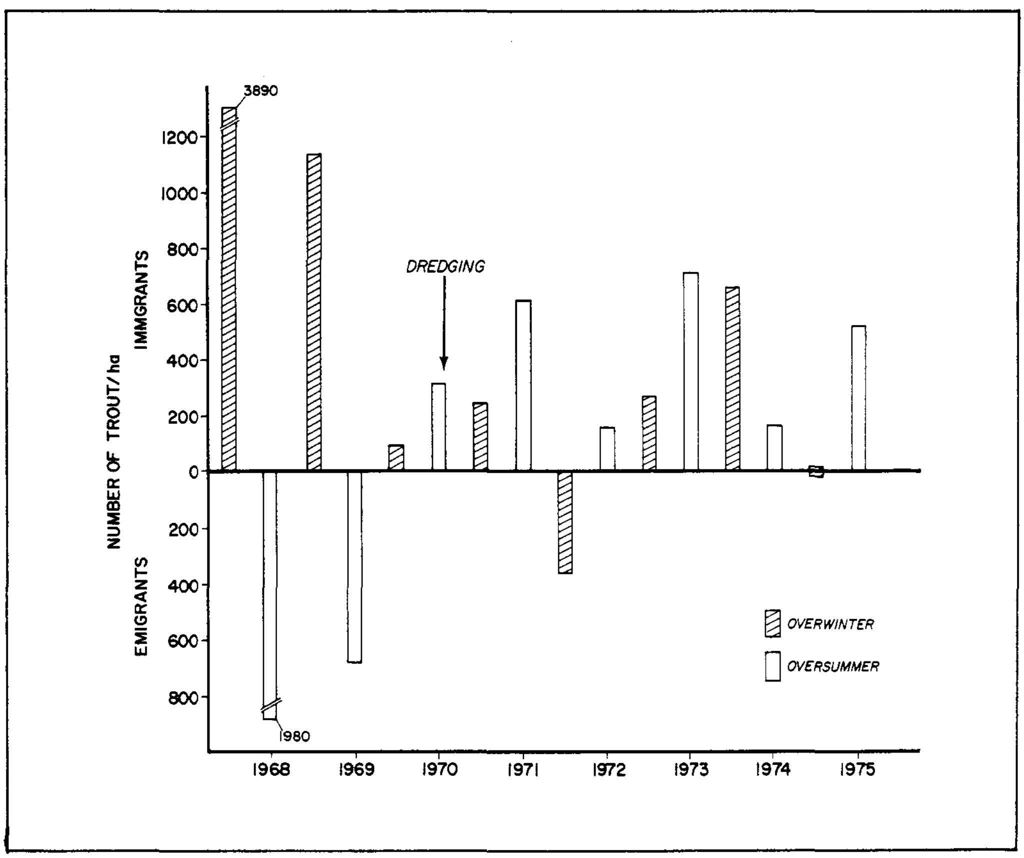


FIGURE 11. *Estimated numbers of brook trout that migrated into or out of Sunshine Springs, 1968-75. Overwinter periods are from October to the following April and oversummer periods are from April to October.*

TABLE 16. *Areas utilized for spawning and numbers of trout redds in Krause and Sunshine Springs before and after dredging.*

Pond and Type of Spawning Area	Gravel Area Used For Spawning (m^2) Before	After	Number of Redds (Range) Before	After
Krause Springs				
Natural	1	21	0-2	20-30
Developed		75		7-13
Both Areas	1	96	0-2*	28-43**
Sunshine Springs				
Natural	19	19	20-25	20-25
Developed		56		12-20
Both Areas	19	75	20-25[1]	38-45[2]

* 1967-70
** 1971-75
1 1967-69
2 1970-75

TABLE 17. *Densities of brook trout fingerlings in fall in Krause and Sunshine Springs before and after dredging.*

Krause Springs Before Year	no./ha	Krause Springs After Year	no./ha	Sunshine Springs Before Year	no./ha	Sunshine Springs After Year	no./ha
1967	26	1972	1,744	1967	20	1971	1,328
1968	141	1973	494	1968	107	1972	1,307
1969	131	1974	168	1969	898	1973	1,081
1970	1,559	1975	781	1970	600	1974	841
1971	241					1975	2,292
Means	420		797		406		1,370

TABLE 18. *Survival rates of brook trout in Krause Springs (1971-75) that were used to estimate numbers of migrant trout.*

Sampling Interval	Spring to fall	Fall to spring	
Mean length of interval	167 days	198 days	
Age of trout	Age 1+	Age 0	Age 1+
Survival			
Mean	50%	33%	46%
Range	33-61%	24-40%	43-52%
Mean daily instantaneous mortality rate	0.00413	0.00560	0.00389

of yearlings (corrected for half year intervals) were:

Year	G
1968	1.417
1969	1.014
1970	1.738
1971	0.177 (year of dredging)
1972	1.242
1973	1.238
1974	0.900
1975	1.103

Growth rates were lowest in 1971, the summer Krause Springs was dredged. By 1972 growth rates were within predredging range. Mean growth rates from 1972 to 1975 were about 20 percent less than the mean for the predredging period, but differences were not significant ($P > 0.05$).

Mean condition factors of brook trout in both ponds declined by about 24 percent from the year before dredging to the year of dredging (Fig. 12). Condition factors then increased during the year following dredging, but in subsequent years they generally remained below predredging means. This comparison may be biased, because resident and immigrant trout could not be separated and both groups were used to compute mean condition factors.

The declines and subsequent recovery in growth rates and condition factors of trout at both ponds closely followed the response of benthic populations to dredging. Since benthic organisms were the primary food of trout it seems reasonable to conclude that growth rates of trout were controlled by density of benthic invertebrates. It is questionable whether trout were growing as fast 4 to 5 years after dredging as they were before dredging, but certainly the large reduction in growth of trout after dredging was only temporary.

Sport Fishery

Fishing pressure and harvest of trout at both study ponds increased substantially after dredging. Mean numbers of fishing trips in 1969-70 at Krause and Sunshine Springs were 28 and 11, respectively (Table 22). Most angling occurred during the first two weeks of the fishing season. After ponds were dredged, fishing pressure increased by nearly fivefold at Krause Springs and by nearly tenfold at Sunshine Springs. Mean catch at Krause Springs increased from 18 to 152 trout/ha and at Sunshine Springs from 69 to 481 trout/ha. Census clerks did not record any brown trout caught from Sunshine Springs, but we suspect this was due to sampling bias.

TABLE 19. *Estimated recruitment rates of trout from spawning in ponds and from immigration.*

	Postdredging Annual Means (no./ha)	
	Krause Springs	Sunshine Springs
Age 0 brook trout in fall	797	1,370
Expected number of age 1 trout in spring at 33% overwinter survival	263	453
Age 1 + immigrants		
Brook trout	642	597
Brown trout	0	121
Total recuitment of age 1+ trout	905	1,171
Percent of age 1+ recruits hatched in pond	29%	39%

TABLE 20. *Food of different size groups of brook trout in Krause Springs before and after dredging.***

Period Collected and Organisms	Less than 114 mm Freq. Occurr.	Less than 114 mm No.	Less than 114 mm Wt.	114 mm–165 mm Freq. Occurr.	114 mm–165 mm No.	114 mm–165 mm Wt.	Greater than 165 mm Freq. Occurr.	Greater than 165 mm No.	Greater than 165 mm Wt.
Predredging									
Oligochaeta	7	*	*				4	*	*
Hirudinea				3	*	1	2	*	1
Pelecypoda	4	*	*	14	7	4	21	3	1
Gastropoda							2	*	*
Amphipoda	88	64	74	95	83	81	98	81	81
Zooplankton	12	11	*	3	*	*			
Chironomidae	57	24	17	82	10	6	58	15	9
Other Diptera	7	*	1						
Corixidae							4	1	*
Trichoptera	15	1	8	7	*	1	6	*	2
Sialidae				3	*	*			
Fish				3	*	7	2	*	5
Miscellaneous							5	4	2
Number of trout		34			36			62	
Postdredging									
Oligochaeta									
Hirudinea									
Pelecypoda							15	1	*
Gastropoda	6	*	*	6	*	*	30	1	*
Amphipoda	76	7	31	74	3	20	85	76	71
Zooplankton	11	62	4	38	72	6			
Chironomidae	59	30	63	65	24	71	65	18	8
Other Diptera									
Corixidae				15	*	1	40	3	2
Trichoptera				3	*	1	5	*	1
Sialidae	12	*	2	6	*	1			
Fish							10	*	18
Miscellaneous	6	*	*				15	1	*
Number of trout		23			39			26	

*less than 0.5%

**Values for frequency of occurrence are percentages of stomachs containing organisms. Values for numbers and weights are percentages of totals.

TABLE 21. *Food of brook trout over 150 mm in length before and after dredging at Sunshine Springs.* **

Period Collected	Predredging No.	Predredging Wt.	Postdredging Freq. Occurr.	Postdredging No.	Postdredging Wt.
Organisms					
Hirudinea	4	19			
Pelecypoda	1	*			
Gastropoda	1	*	24	2	*
Amphipoda	31	14	66	16	12
Chironomidae	49	12	55	75	26
Other Diptera			3	*	*
Corixidae	11	3	24	1	1
Trichoptera	1	1	24	2	7
Fish	2	50	14	1	55
Miscellaneous	2	1	20	2	*
Number of fish	79			36	

*less than 0.5%
**Values for frequency of occurrence are percentages of stomachs containing organisms. Values for numbers and weights are percentages of totals.

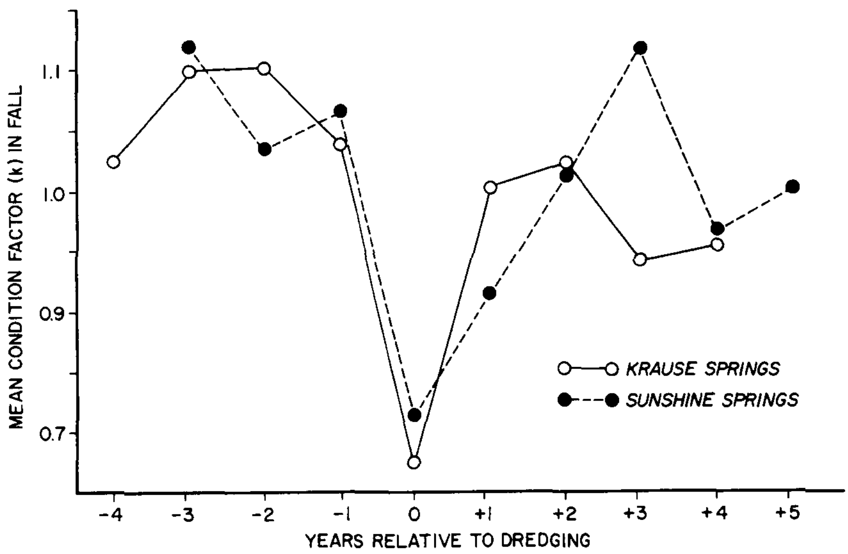


FIGURE 12. *Variations in mean condition factors of brook trout in fall, Krause and Sunshine Springs, 1967-75. Means were computed from all brook trout 127 to 226 mm in total length.*

Exploitation rate* at Krause Springs was only 16 percent in 1975, so that there could have been substantially more fishing without overharvesting the population. The exploitation rate at Sunshine Springs in 1975 was 57 percent (481/846). Between April and October there was a large movement of trout into the pond and in October the density of Age 1 and older trout exceeded the spring density (1,345 vs. 846 trout/ha). It is evident that in Sunshine Springs where immigration played an important role in maintaining the population, exploitation rates did not accurately assess the impact of fishing mortality. Obviously, Sunshine Springs could have sustained a greater catch of trout without overharvesting the population. Therefore, at both ponds harvest and fishing pressure increased substantially following dredging, but perhaps more importantly, both ponds could have sustained greater use without any deleterious effects on their trout populations.

COMPARISONS WITH OTHER SPRING PONDS

In the previous section we used data from 1975 as indicative of the postdredging status of Sunshine and Krause Springs. Before making final conclusions regarding overall effects of dredging, two questions should be posed: first, "Had growth rates and densities of trout populations in the study ponds stabilized by 1975 or were the populations still in a transition phase?", and second, "Were trout populations in Krause and Sunshine Springs typical of other ponds and can we expect similar responses to dredging at other sites?" To provide at least partial answers to these questions, we have compared various population parameters of trout in study ponds with those of other dredged and unaltered ponds.

Growth

Mean weights of brook trout in 1975 at the study ponds were within ranges found in other dredged and undredged ponds in the Langlade area (Fig. 13). Growth in length of brook trout in study and reference ponds was also similar (Append. III). Variations in growth rates among populations were partly dependent upon population density. We used mean size of spring yearlings to illustrate differences in growth rates among populations, because these are the

*Number of trout caught divided by density of spring population.

most reliable growth data we have from all populations.

As population biomass increased, size of spring yearlings decreased (Fig. 14). However, the decrease in growth was not large compared to the change in biomass. With a tenfold increase in biomass there was only a 21 percent decrease in mean size of yearlings. Yearlings in Krause and Sunshine Springs were larger before dredging than afterwards, and at both ponds yearlings in 1975 were below the fitted line (Fig. 14). These data suggest that growth rates of age 1 trout in the study ponds were well below average, considering their relative densities. Presumably, growth rates of age 2 and older trout in study ponds were also less than that of trout in reference ponds. If benthic communities in study ponds continue to increase, an improvement in growth rates of trout is likely. Providing growth rates in study ponds approach average rates, a 10-15 percent increase in trout biomass can be anticipated.

Density and Biomass

Densities and biomass of trout in spring ponds can vary greatly. We have found as few as 448 trout/ha in Rabe Lake and up to 7,590/ha in Maxwell Springs (Table 23). Similarly, biomass estimates have ranged from 18 to 282 kg/ha. Compared with other dredged or unaltered ponds, Krause Springs supported a relatively small population of trout, while density and biomass of trout in Sunshine Springs was close to the average for all ponds (Table 23).

Density and age structure of brook trout populations were influenced by the extent of available spawning areas and levels of immigration. When ponds were ranked according to rates of total recruitment, effects of spawning and immigration were apparent. Clubhouse Springs supported one of the smallest populations of trout and there were no spawning areas in this pond; all trout immigrated from connecting streams (Table 24). At the other extreme was Hogelee Springs #2, which had a large spawning area that extended along 100 m of the shoreline. In addition, there may have been some immigration into this pond. Of the ponds with intermediate trout densities, Krause Springs had the fewest number of redds each fall and the smallest downstream area from which to draw recruits. Spawning areas in Sunshine and Hoglot Springs were not greatly different in size, the main differences were in rates of immigration. In 1974 and 1975 average annual rate of immigration into Sunshine Springs was 520 trout/ha and the average for Hoglot Springs was about 2,600 trout/ha (Carline 1975).

We have shown that recruitment rates and living space can limit standing crops

TABLE 22. *Summary of fishery statistics at Krause and Sunshine Springs before and after dredging.*

	Means of 1969 & 1970	1975
Krause Springs		
Angler hr./ha	100	489
Catch: trout/ha.	18	152*
Catch Rate: trout/hr.	0.18	0.31
Yield: kg of trout/ha	1.3	15.5
Mean length of trout (mm)	208	211
Number of trips	28	124
Sunshine Springs		
Angler hr./ha	94	896
Catch: trout/ha	69	481**
Catch Rate: trout/hr.	0.73	0.54
Yield: kg of trout/ha	6.8	40.4
Mean length of trout (mm)	206	198
Number of trips	11	182

*all brook trout except for 14 rainbow trout
**all brook trout

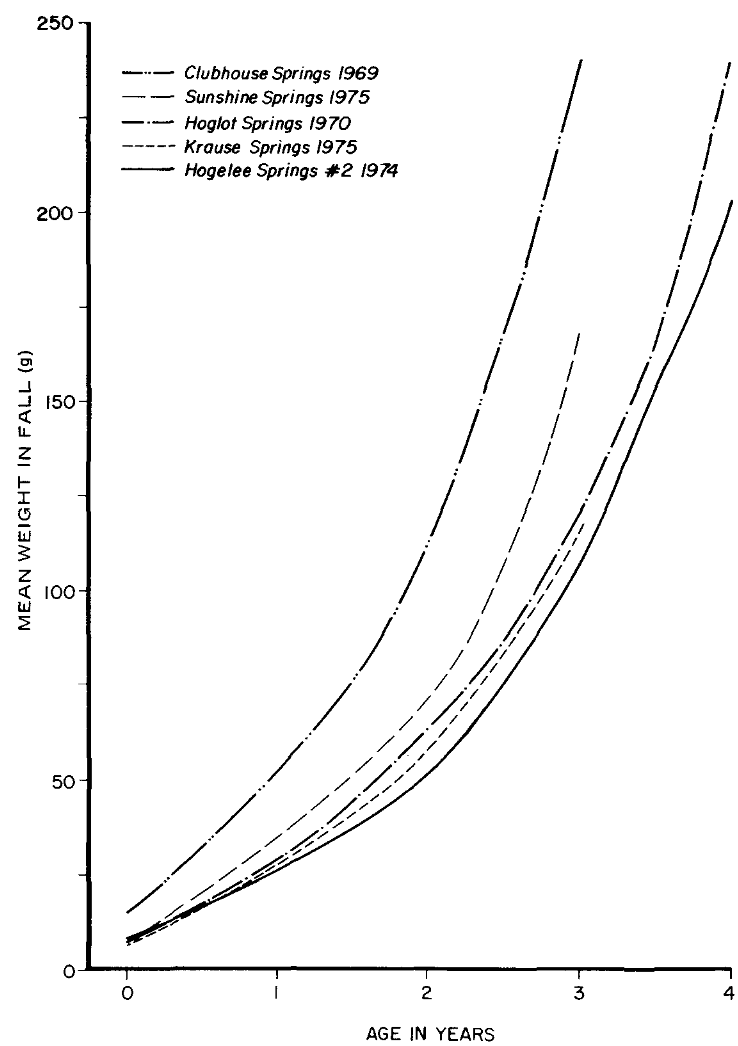


FIGURE 13. *Growth rates of brook trout in five spring ponds.*

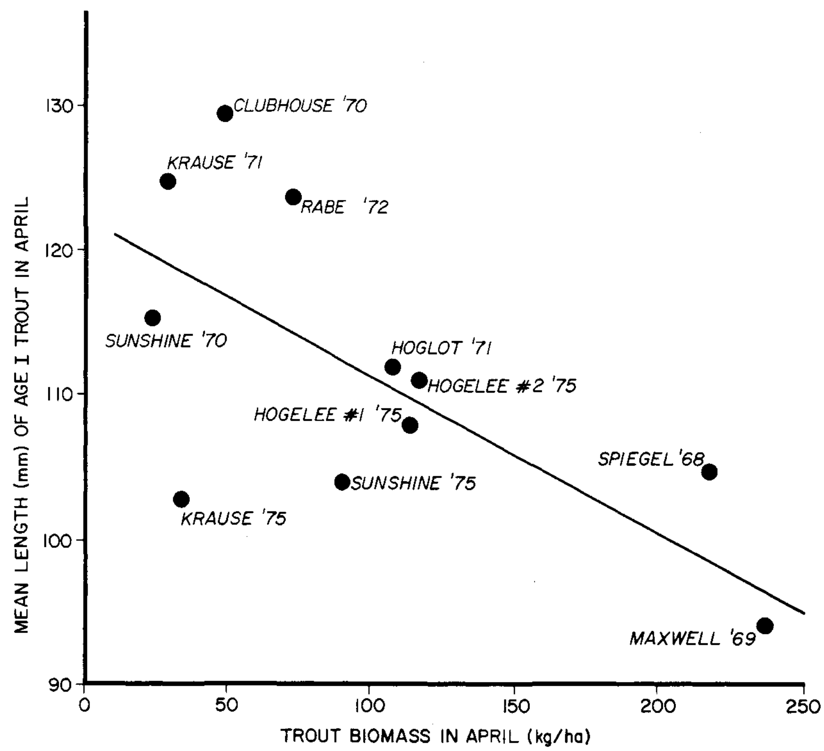


FIGURE 14. *Relationship between trout population biomass in spring and mean lengths of Age 1 brook trout in April. (Data from nine different populations. Line fitted by regression.) Year of estimate indicated next to each symbol.*

TABLE 23. *Density and biomass of trout populations in dredged and undredged spring ponds.**

Pond and Years of Estimates	Year Dredged	Species	Number of Estimates	Trout Density (no./ha) Mean	Trout Density (no./ha) Range	Trout Biomass (kg/ha) Mean	Trout Biomass (kg/ha) Range
Krause 1974, 1975	1971	Brook	5	991	480-1,486	32.1	18.0-40.2
Sunshine 1974, 1975	1970	Brook Brown	5	1,708	828-3,240	89.7	68.0-115.5
Hogelee #1 1975	1969	Brook	1	1,891	–	114.9	–
Hogelee #2 1974, 1975	1969	Brook	2	3,321	2,906-3,736	113.8	97.7-129.8
Rabe 1973	1968	Brook Rainbow	1	448	–	65.8	–
Spiegel 1968, 1969, 1970	1963	Brook Brown	9	3,211	1,586-6,475	164.2	85.6-282.6
Hoglot 1968, 1969, 1970, 1971, 1972	1963	Brook	9	3,766	1,554-6,850	102.6	36.8-154.1
Clubhouse 1968,1969, 1970, 1971, 1972	–	Brook Brown	9	917	541-1,836	50.8	28.1-86.1
Maxwell 1969, 1970, 1971, 1972	–	Brook	8	4,555	1,815-7,590	147.9	45.2-237.8

* Data on brook trout populations in Hoglot, Clubhouse and Maxwell Springs taken from Carline (1975). Additional data on trout populations in Rabe Lake, Spiegel Springs and Hogelee Springs #1 & 2 are given in Appendixes III, IV and V.

TABLE 24. *Comparison of fall age structure and density of brook trout populations in ponds with different recruitment rates. Ponds are arranged in order of increasing recruitment rates.*

	Clubhouse	Krause	Sunshine	Hoglot	Hogelee #2
Age	Means of 1968 to 1971	1975	1975	Means of 1968 to 1971	1974
0	195*	781	2,285	1,928	4,125
1	293	278	701	1,730	944
2	80	317	244	723	577
3	7	70	15	89	175
4+	2	8	5	8	52
Total	577	1,454	3,250	4,478	5,873

*density in no./ha

TABLE 25. *Summary of fishery statistics from selected spring ponds in Langlade County. All ponds are public waters except for Maxwell Springs.*

Pond and Year	Angler hr./ha	Catch (no./ha) Species	Catch (no./ha) Total	Trout/hr.	Mean Length (mm)	Yield (kg/ha)
Rabe Lake						
1969	1,057	505 Brook 61 Rainbow*	566	0.54	201 218	48
1970	1,139	461 Brook 31 Rainbow*	492	0.43	201 224	43
1972	2,339	248 Brook 1,127 Rainbow**	1,375	0.59	216 208	96
1975	1,242	139 Brook 554 Rainbow**	693	0.56	229 226	92
Clubhouse Springs						
1969	1,057	579 Brook 21 Brown	600	0.57	218 218	63
1970	1,403	391 Brook 21 Brown	412	0.29	213 272	40
1972	832	299 Brook 7 Brown	306	0.37	203	24
1975	2,191	516 Brook 292 Brown	808	0.37	221 284	205?
Hoglot Springs						
1969	835	924 Brook	924	1.11	183	46
1970	526	390 Brook	390	0.74	193	22
1972	400	217 Brook	217	0.54	188	14
Hogelee Springs #1&2	1,428	1,343 Brook	1,343	0.94	198	114
Maxwell Springs						
1969	188	333 Brook	333	1.77	272	60
1970	153	319 Brook	319	2.08	231	36

*escaped from private fish hatchery
**lake was stocked by DNR

of trout in spring ponds. The interrelationship between these two factors can be illustrated by examining mean biomass of trout in relation to mean depth of ponds (Fig. 15). At mean depths of 0.5 m or less, living space is the primary limiting factor and as pond depths increase, trout biomass increases, provided recruitment is not limiting. Those ponds with small or no spawning areas and low rates of immigration were characterized as having insufficient recruitment (Rabe, Clubhouse and Krause Springs). All other ponds had moderate to large spawning areas plus some had moderate to high levels of immigration. We could have plotted mean numbers of trout or mean numbers of legal size trout and the relationship would have been similar. Dredging served to alleviate living space as a limiting factor, but potential production of dredged ponds was realized only when there was sufficient recruitment.

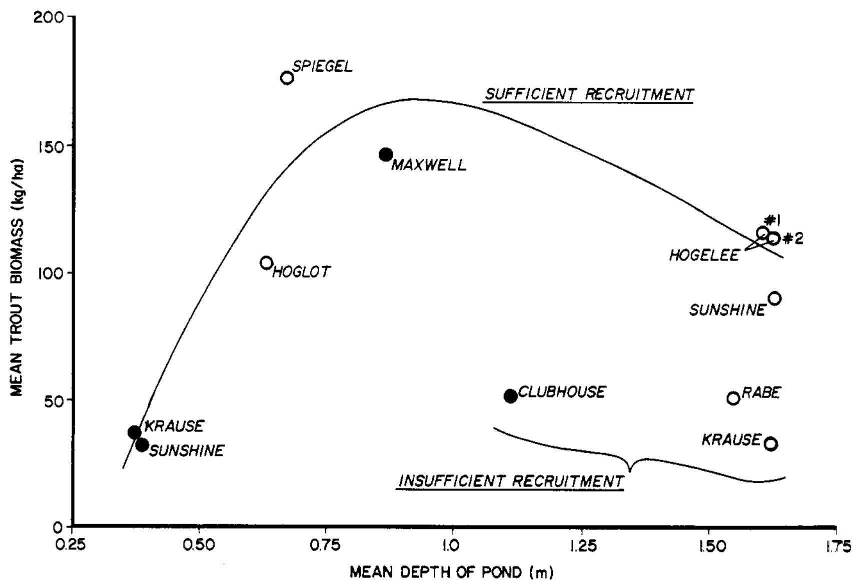


FIGURE 15. *Relationship between mean depths of ponds and trout biomass. (Values taken from Tables 1, 2, 12, 15, and 23). Ponds with little or no spawning area were categorized as having insufficient recruitment. Solid symbols designate undredged ponds.*

Sport Fishing Pressure and Yield

There was considerable variation in fishing pressure and harvest among spring ponds in the Langlade area (Table 25). Ponds with convenient access and ones large enough to accommodate boat anglers had the highest pressure, e.g. Rabe Lake and Clubhouse Springs. Fishing pressure (896 hr/ha) and catch (481 trout/ha) from Sunshine Springs were well within the range of other ponds. Pressure (489 hr/ha) and catch (152 trout/ha) from Krause Springs were low compared to other public waters. Yields of brook and brown trout ranged from 14 to 205 kg/ha. The highest value, from Clubhouse Springs in 1975, is suspect. Catch rates of brown trout in 1975 were 7 to 16 times greater than in previous years. Biased estimates of catch rates could have led to inflated yield estimates. We consider a range of 20 to 100 kg/ha as realistic yields from spring ponds. Yield of trout from Krause Springs in 1975 (15.5 kg/ha) was well below the average of all ponds while yield from Sunshine Springs (40.4 kg/ha) was near the average.

The low fishing pressure at Krause Springs was partly due to lack of public awareness. During the 1975 creel census we learned that a considerable number of anglers at Rabe Lake, which is only 200 m from Krause Springs, did not know Krause Springs had been dredged or that it was within easy walking distance of the Rabe Lake parking lot. We suspect that as more anglers find out about Krause Springs, fishing pressure will increase.

Based on the foregoing comparisons we conclude that trout populations in study ponds are not atypical and future changes in populations are not likely to be marked. Sunshine Springs supported a biomass of trout similar to other dredged ponds that had adequate spawning areas. The trout population in Krause Springs was within the range of other ponds in which recruitment was limiting. Pressure at Krause Springs was low, but we anticipate greater use in the future. Both ponds could have sustained greater fishing pressure without overharvesting the populations.

DISCUSSION

RELATIVE PRODUCTIVITY OF SPRING PONDS

Standing crops of wild trout in northern Wisconsin spring ponds are among the highest reported values for salmonids in small lakes. We have compared our data with a sample of representative lakes under 20 ha (Table 26). Among those lakes that supported wild populations of trout, some Colorado beaver ponds (Rabe 1970) appeared to be at least as productive as Wisconsin spring ponds. Standing crops of brook trout in several beaver ponds exceeded 200 kg/ha and all of these ponds had large spawning areas. Among lakes that were stocked, several New York state farm ponds supported over 200 kg/ha of trout and in a eutrophic reservoir in Oregon (Higley and Bond 1973) biomass of juvenile chinook salmon (*Oncorhynchus tshawytscha*) reached 140 kg/ha.

Among the studies we used to compare with Wisconsin spring ponds, we found large variations in growth rates of trout. Genetic differences undoubtedly were responsible for some variation, but population densities appeared to be the major controlling factor. In Colorado beaver ponds that had large spawning areas, population densities were high and growth rates relatively low (Rabe 1970). In beaver ponds with low levels of recruitment, standing crops of trout were usually less than 50 kg/ha and growth rates were high. Similarly, Campbell (1971) concluded that growth rates of wild brown trout in Scottish lochs were a function of population density. Those lochs with inlets or outlets that provided suitable spawning substrates supported dense populations of slow-growing trout. In our study, fastest-growing populations were in ponds with no spawning areas. Conversely, the smallest yearling and older brook trout that we have found were in Maxwell Springs in 1969 when standing crops of trout were well above 200 kg/ha.

Average annual yields of wild trout from Wisconsin spring ponds were well above any other lake fishery for wild trout. Yields from Minnesota lakes stocked with trout and from a small Ontario impoundment (McCrimmon and Berst 1961) were within the range of yields from spring ponds (Table 26). In addition to supporting large stocks of trout, spring ponds were heavily fished. Average annual pressure was about 1000 hr/ha. With the exception of several Minnesota lakes, fishing pressure at other sites was less than 500 hr/ha. High pressure on spring ponds was due in part to their small size. When we plotted fishing pressure against surface area for a wide range of lakes we found a significant inverse correlation. Nevertheless, yields of trout comparable to those of spring ponds could have only been achieved in some beaver ponds and farm ponds (Eipper 1964), because these were the only waters that supported large enough populations to provide yields over 50 kg/ha.

We attribute the relatively high standing crops of trout in spring ponds to rich benthic fauna. To compare our data with those of other studies, it was necessary to convert some values to weights. We assumed the specific gravity of benthic organisms was 1.05 and dry weights were 20 percent of wet weights. Annual benthic biomass in Wisconsin ponds ranged from 30 to 66 g/m. For other studies, highest benthic biomass of 65 g/m^2 was in Third Sister Lake, Michigan, when no fish were present (Table 27). In Colorado, Parvin Lake supported 58 g/m^2 of benthic organisms and those beaver ponds (Rabe 1970) with low densities of brook trout averaged 47 g/m^2 of benthos. In other small lakes, benthic biomasses were well below those of spring ponds. We also examined benthic biomass in larger lakes and reservoirs and, in general, values were less than 10 g/m^2.

High productivity of benthic organisms in Wisconsin spring ponds is probably related to high levels of primary production by macrophytes and periphytic algae. Water clarity tends to be high throughout the year, because surface runoff is usually insignificant. In most spring ponds light penetrates to the bottom at all depths, except during periods of ice cover. Aquatic macrophytes frequently form dense beds and cover large portions of ponds. Macrophytes support relatively large stocks of benthic invertebrates. It has been shown that attachment surfaces are important for supporting benthic invertebrates (Andrews and Hasler 1944; Wohlschlag 1950; Pardue 1973). In addition, macrophytes provide habitat for forage fish, particularly the brook stickleback, sculpin, and mudminnow. Where macrophytes are absent, it is common to find mats of filamentous algae and benthic organisms are positively associated with high production of epiphytic algae (Kajak and Rybak 1966; Hargrave 1970).

There were relatively high concentrations of nutrients in the ground water that supplied our study ponds. Presumably ground water entering other ponds in the Langlade area was of similar quality. At Sunshine Springs the estimated annual inputs of total phosphorus and nitrogen were 1.6 and 150 $g/m^2/yr$ and at Krause Springs they were 5.2 and 278 $g/m^2/yr$, respectively. At these loading rates, in lakes with relatively long exchange times, e.g. 1 year or more, extreme eutrophy would probably result (Dillon 1975). Exchange rates in study ponds were 4 to 5 days, hence, nutrient concentrations did not build up. However, the constant supply of nutrients undoubtedly promoted high levels of primary production.

OTHER DREDGING PROJECTS

Large-scale dredging as a lake rehabilitation technique is a relatively recent innovation (Pierce 1970). In general, rehabilitation projects have been aimed at improving recreational opportunities. From a survey of 49 projects, Pierce (1970) concluded that "there is no finished lake-dredging project in the upper Midwest from which complete and reliable data can be obtained on the effect of lake dredging on the total lake environment". This dearth of information on inland lake dredging was in part responsible for the initiation of our study. However, more recently, several studies have been completed on the effects of hydraulic dredging.

The entire basin of Long Lake (59 ha) in Michigan was dredged to improve conditions for swimming and boating (Spitler 1973). Prior to dredging, the lake was subject to frequent winterkills of fish. Lake volume was increased by 192 percent and mean depth from 0.7 to 2.0 m. Heavy growths of macrophytes were eliminated and since 1965 no winterkills have occurred.

Two Florida lakes were partially dredged to increase benthic productivity by converting muck to sand bottoms (Wilbur and Langford 1972). In Lake Carlton (155 ha), sand was dredged from the middle of the lake and deposited at several sites near shore, creating submerged sand islands over the muck bottom. A total of about 4 ha were developed. In Trout Lake (42 ha) about 7 ha of muck bottom were dredged and

TABLE 26. *Average standing crops, fishing pressure, and yields of salmonids from selected lakes less than 20 ha in surface area. Ranges of values are given in parentheses.*

Lake Name or Type No. and Location	Type of Lake	Years	Species and Strain		Surface Area (ha)	Standing Crop of Trout (kg/ha)	Angler Yield (kg/ha)	Fishing Pressure (hr./ha)	Author
Spring ponds (8), Wisconsin	Natural	1968-1975	Brook Brown	(W)* (W)	0.4-1.0	102 (18-238)	57 (14-114)	1,006** (400-2,191)	Present study
Jo-Mary Pond, Maine	Natural	1960, 1966, 1968	Brook	(W)	15	5[1] (1-12)	5 (2-8)	94 (48-131)	Andrews (1973; pers. comm.)
Subalpine lakes (2), Wyoming	Natural	1962	Brook	(W)	3	(18-31)	(7-15)	(101-148)	Garofalo (1964)
Lochs (4), Scotland	Natural	?	Brown	(W)	2-15	–	2-15	–	Campbell (1971)
Beaver Ponds (17), Colorado	Natural	1954-1955	Brook	(W)	0.2	(6-273)	–	–	Rabe (1970)
Farm Pond, Ontario	Impoundment	1951-1960	Brook Rainbow	(W+S)*	0.6	58[2]	40	336	McCrimmon and Berst (1961)
Farm Ponds, New York State	Man-Made	1952-1956	Brook Rainbow	(S) (S)	up to 0.8	(75-270)	–	–	Eipper (1964)
Farm Ponds (8), Ontario	Man-Made	1959-1961	Brook	(S)	0.1-0.2	69 (24-111)	(8-11)	62	Johnson (1964)
Whistler's Bend, Oregon	Impoundment	1962-1963	Rainbow	(S)	13	28[3]	–	–	Coche (1967)
Happy Valley Reservoir, Oregon	Impoundment	1961-1962	Chinook Salmon	(S)	7.5	121-142[3]	–	–	Higley and Bond (1973)
Willard, Pleasant, and Perch Lakes, Minnesota	Natural	1957-1963	Brook Rainbow	(S) (S)	2.8-8.9	–	34 (9-69)	709 (319-1,210)	Micklus and Johnson (1965)
Crecy Lake, New Brunswick	Natural	1952-1963	Brook Rainbow	(W+S) (S)	20	–	10	79	Smith (1968)
East Fish Lake, Michigan	Natural	1951-1962	Brook Rainbow	(S) (S)	6.5	18[1]	21	225	Alexander and Shetter (1969)

*W = wild; S = stocked
**includes only public waters
1 average of April estimates
2 single estimate
3 maximum biomass

TABLE 27. *Comparison of benthic biomasses in small lakes. Some of the values that were reported as volume or dry weights were converted to wet weights.*

Lake Name or Type, No. and Location	Benthic Biomass Wet Weight (g/m^2)	Type of Estimate	Author
Krause, Sunshine & Maxwell Springs, Wisconsin	30-66	Range of annual means. Postdredging data not included.	Present study and Carline (1975)
Beaver Ponds (17), Colorado	17-47	Means from ponds with low and high densities of trout.	Rabe (1970)
Subalpine Lakes (2), Wyoming	5-16	Range of three-month means.	Garofalo (1964)
Crecy Lake, New Brunswick	7	Mean of samples taken 1951-56. Lake fertilized in 1951.	Smith (1961)
Experimental Ponds (4), Michigan	3-10	Range of annual means from two unfertilized and two fertilized ponds.	Patriarche and Ball (1949)
Parvin Lake, Colorado	58	Annual mean	Buscemi (1961)
Third Sister Lake, Michigan	20-65	Range of three-year means; highest value recorded in absence of fish.	Ball and Hayne (1952)

converted to sand or sand-muck mixtures. At both lakes there was no apparent change in water quality after dredging (Crumpton 1974). In Trout Lake the most numerous invertebrates, chironomid and *Chaoborus* larvae and oligochaetes, declined in density immediately after dredging. About one year after alteration, density and diversity of benthic organisms in sand substrates were greater than in unaltered muck bottom.

Lake Trummen in Sweden, a highly eutrophic lake (100 ha; mean depth = 1.1 m), had received large volumes of sewage until 1958 (Björk et al. 1972). Lake conditions did not improve after pollution abatement and part of the basin was dredged in 1970-71 to remove nutrient-rich sediments. Lake volume was increased by 70 percent. Nutrient concentrations in the water column decreased after dredging and blue-green algae were replaced by green algae (Bengtsson et al. 1975; Cronberg et al. 1975). Benthic invertebrates increased from 1,000 to 2,000/m^2 before dredging to well over 10,000/m^2 afterwards; oligochaetes accounted for much of this increase (Andersson et al. 1975). Documenting responses of the fish community was complicated by a winterkill prior to dredging.

In our study major physical effects of dredging were associated with increases in pond volumes, temporary elimination of macrophytes, and changes in bottom types. Winterkill was not a problem in these shallow ponds because of the large inflows of oxygenated ground water. Development of benthic communities four to five years after dredging was in part related to nature of bottom types. Declines in numbers of *Hyalella* and leeches may have been related to reductions in organic content of sediments. As aquatic macrophytes continue to increase in area and density, further increases in benthic invertebrates can be anticipated. Chironomids will probably respond positively to further development of *Chara* beds and increases in *Anacharis* will likely lead to improvement in densities of snails. The recovery of invertebrates associated with organic sediments is likely to be slow.

In Lake Trummen (Andersson et al. 1975) and in our study, oligochaetes, primarily Tubificidae, increased dramatically after dredging. Andersson et al. (1975) suggested that the increase in oligochaetes may have been due to a decline in fish predation because of winterkill. In Krause and Sunshine Springs trout densities remained the same or increased after dredging. It is unlikely that trout predation had any effect on oligochaete densities. We suspect that densities of sticklebacks in 1975 were well below their predredging levels. It is conceivable that stickleback predation maintained relatively low levels of oligiochaetes prior to dredging. However, we feel the most plausible explanation for high densities of tubificid following dredging was the reduced density of predaceous invertebrates.

The entire basins of Krause and Sunshine Springs were dredged and benthic populations were reduced by over 90 percent. If parts of the basins had been unaltered, recolonization of dredged areas would have probably been accelerated. Presumably, in lakes where only small portions of basins are dredged, near complete recolonization could occur within two years, whereas in our study after five years it appeared that recolonization was continuing. Projections of quantitative changes in benthic communities following dredging will depend upon anticipated changes in substrates and water quality. Where macrophytes are replaced by sand or muck, benthic biomass may not attain predredging levels. Conversion from muck to sand is likely to lead to increases in density and diversity of organisms, a response one also can anticipate from improvement of water quality.

SEDIMENTATION PROCESSES

Cost-benefit analyses of dredging are contingent upon "economic life" of the project, i.e., how long before the pond refills and reverts to predevelopment con-

TABLE 28. *Total alkalinity and specific conductance from surface waters of selected Wisconsin spring ponds. Cores of sediments were sampled at 15 cm intervals and analyzed for percentage total organic matter (TOM).*

County	Pond	Total Alkalinity (mg/l as $CaCO_3$)	Specific Conductance (μmhos/cm^2)	Presence of Peak TOM in Sediments	Depth of Peak TOM From Surface (m)	Depth of Peak TOM From Interface (m)	Max. TOM (Percent)
Burnett	Culbertson	78	151	+	2.0	1.4	75
	Dogtown	36	80	–	0.6	0.3	28
Douglas	Bergen	40	90	+	1.7	0.8	88
	Rifle Range	38	85	+	0.9	0.3	40
Forest	Camp One (1)	123	248	+	2.0	0.6	85
	(2)			+*	1.5, 2.7	0.2, 1.4	98, 100
Marathon	Spiegel	165	336	+	0.9	0.6	32
	Totten	147	302	+	1.2	0.6	86
Langlade	Denault	206	416	+	2.4	0.6	52
	Hogelee #1	172	318	–	0.9	0.6	25
	Hogelee #2	172	338	+	2.0	1.1	90
	Lambert	121	225	+	1.7	0.8	72
	Nixon	181	361	+	1.4	0.8	100
	Rabe (1)	183	357	+	2.4	1.2	90
	(2)			+	2.4	1.2	76
Sawyer	Porcupine	76	154	–	3.0	2.4	80
Washburn	Sawyer	120	230	–	1.5	0.3	45

*Two peak TOM's in this core.

dition. One way to determine duration of dredging projects is to examine rates of filling in the past and the processes involved.

Spring ponds in Wisconsin were formed by glacial activity about 10,000 years ago. It is likely that most spring ponds are now less than half their original sizes. Rose (1977) took a series of soil borings to determine original basin sizes of our study ponds. The presedimentation area of Sunshine Springs was 0.77 ha, or twice as large as surface area after dredging (0.38 ha). Its postdredging volume was about 45 percent of the estimated presedimentation volume. At Krause Springs shoreline encroachment was even more extensive. Original area was about 3.5 times present area and volume was five times greater than at present. Sunshine and Krause Springs are not unique. Most spring ponds are surrounded by extensive wooded lowlands or meadows. These areas of saturated soils represent encroached shorelines.

Filling of lakes is usually associated with the input of alloct' ɔnous materials via surface drainage. Filling of spring ponds may be more dependent upon autocthonous materials and processes occurring within the ponds rather than upon external forces. We believe that aquatic macrophytes play an important, if not the major role, in filling of spring ponds.

Chara and *Anacharis*, the dominant plants in hardwater ponds, formed dense stands and biomass peaked in September. In Clubhouse Springs, *Chara* beds covered at least 40 percent of the pond bottom and in September, 1972, the standing crop was about 15,000 g/m² (fresh weight). Much of this plant material dies off overwinter, hence a substantial amount of organic material is deposited in the sediments. Bacterial decomposition of plant material may not be significant because of relatively low water temperatures. For instance, in early August when pond temperatures are warmest, we measured temperatures at the mud-water interface at Maxwell Springs. Pond depths and mean temperatures were:

0.46 m	11.1°C
0.60 m	10.0°C
2.4 m	7.1°C

Temperatures were cooler within beds of vegetation then in exposed areas because of shading. We estimated that mean annual temperature at the mud-water interface was 7°C at 1.5 m.

In 1966, core samples of sediments were collected from 15 spring ponds as part of the DNR Bureau of Fish Management's survey of spring ponds in need of dredging. Analyses of these samples have provided at least circumstantial evidence that aquatic macrophytes play an important role in the filling process. Sections of cores were removed at 15-cm intervals and analyzed for total organic matter (TOM) and some sections were analyzed for carbonates (expressed as calcium carbonate). By weight, calcium carbonate and TOM together comprised 71 percent of sediments. There was considerable variation within and among cores. Calcium carbonate ranged from 6 to 88 percent and TOM ranged from about 1 to 99 percent.

There was a persistent pattern in change of TOM with respect to depth within 13 of 17 cores (Table 28). TOM was lowest at the bottom of the cores, just above mineral soils. TOM increased with decreasing depth, reached a maximum, and then decreased near the top of the core (Fig. 16A). We used data from cores with a peak TOM and constructed a generalized curve (Fig. 16B). TOM began to increase rapidly at depths of 2.0 to 2.5 m, the depths at which macrophytes begin to colonize spring ponds. TOM peaked at 1.8 m, the depth at which plants begin to form dense beds.

The decrease in TOM in sediments near the interface may be due to increased bacterial decomposition. In addition to deposition of organic matter, there is a continual precipitation of calcium carbonate. Because plants accelerate precipitation of marl by removing carbon dioxide and bicarbonate ions from the water, the reduction of TOM in surface sediments may simply reflect increased rates of marl precipitation, not a decrease in rates of organic deposition.

We conducted several experiments in 1973 to test the hypothesis that aquatic vegetation can have a significant effect on rates of calcium carbonate precipitation in spring ponds. Several water quality parameters were monitored on a 24-hour basis. Outlets of Clubhouse and Sunshine Springs were monitored for 24 hours on days of full sunshine and solid overcast. Clubhouse Springs supported a high biomass of *Chara* and Sunshine Springs served as a control, because it had been dredged two years prior and there was little plant growth in the pond.

There was a distinct diel pulse of calcium ions in Clubhouse outlet during days of full sunlight. Concentrations of calcium were lowest in late afternoon, when concentrations of dissolved oxygen and pH were highest. Thus, when photosynthetic activity was highest calcium carbonate precipitation was most pronounced. At Sunshine Springs there was no diel change in calcium concentration in either sunlight or overcast days, nor was there any diel pulse in calcium at Clubhouse outlet during overcast days. We estimated with a full day of sun that total precipitation of calcium carbonate was 27 kg/ha/day at Clubhouse Springs, about half of which was due to photosynthesis. In 1975-76, further experiments were conducted at these same ponds and peak rates of precipitation were 62 kg/ha/day at Clubhouse Springs (M. Reif; pers. comm.). If there were full sunlight every day of the open water period, the estimated annual precipitation rate would be 14 metric tons/ha. Based on our studies and those of M. Reif, it was apparent that *Chara* had a marked effect on marl formation in spring ponds. As ponds become shallower, beds of *Chara* tend to increase in both area and density. Hence, we suggest that rates of filling through organic accumulations and marl formation will be a function of pond depth.

Rates of allocthonous inputs will no doubt influence sedimentation processes, but we have no measure of these rates. In some ponds large amounts of woody debris have been removed during the dredging operation. Under certain circumstances leaf litter could also be a major source of sedimentation. When pond outlets become clogged with debris and surface waters do not readily flow out, floating material is retained in the pond rather than transported out. If outlets remain clogged, floating leaves and other debris eventually become water-logged and sink. In this regard beaver activity on pond outlets could greatly enhance accumulation of allocthonous material by preventing transport out of the pond. Impairment of outlet flow for just a few weeks in fall could result in significant deposition of organic matter.

We have suggested some mechanisms that influence the filling process. It is apparent that we do not know what annual rates of sedimentation are, but it is clear that under the right circumstances, rates of filling can be quite rapid and a meter or more of sediments could easily accumulate in less than 100 years. Therefore, we suggest that projection of the economic life of dredging programs be conservative.

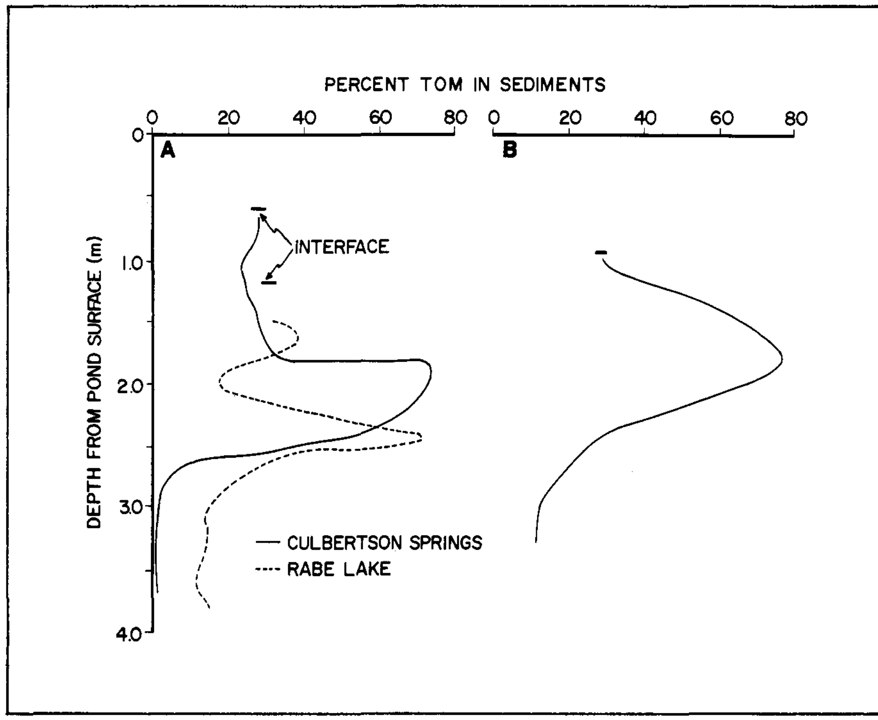


FIGURE 16. *Variations in percentage total organic matter (TOM) of sediments with respect to depth of sediments from pond surface. Curves for Culbertson Springs and Rabe Lake were fitted to actual data (A). The curve in panel B was fitted to data from average values of 12 cores in which there was a single peak in TOM.*

ECONOMIC EVALUATIONS

To evaluate the economics of dredging we have compared the increased annual gross expenditures of anglers after ponds were dredged with the average annual cost of the projects. Numbers of angler trips were estimated from the 1975 creel survey. Daily gross expenditures of spring pond fishermen were based on data projected from other studies. Typically, in benefit-cost analyses of public works projects, net income derived from the project over its estimated life span is compared to costs of project construction and maintenance. Net income (or net value) is the difference between total income from goods and services generated by the project and the costs of those goods and services. Although we shall equate gross expenditures with benefits, it should be emphasized that gross expenditures are not equivalent to net income. However, gross expenditures do reflect the level of interest in, and present satisfaction with, the resource (Gordon et al. 1973). Thus, in a broad sense, angler gross expenditures for fishing in the developed ponds constitute income realized by the project.

Project costs include materials, fuel, and all labor for access development, spoil area construction, dredge operation, and supervision. Depreciation of the dredge (1969-72) was based on \$10/hr of operating time. In later years this rate was increased slightly. If easements or outright purchase of land was necessary for a project, these expenditures were not included in the total project cost.

Krause and Sunshine Springs were treated as a single project in comparing angler gross expenditures and project costs. These ponds are similar in size and accessibility, and development costs were nearly identical. Total project cost for both sites was \$22,600.

Compared to other DNR dredging projects, costs of developing Krause and Sunshine Springs were relatively high. On a cost per unit volume, i.e., cost to increase pond volume by 1 m^3, statewide values ranged from \$0.52 to 2.67/m^3, respectively.

Increases in pond volumes and size of dredge used had considerable bearing on unit costs. In general, there was an inverse relationship between increases in pond volume and unit costs (Fig. 17). The DNR owns and operates two dredges, one has a 15-cm intake (6 inches) and the other a 20-cm intake (8 inches). Unit costs of projects utilizing the 20-cm intake dredge were usually lowest at any given increase in pond volume. Costs of developing Krause and Sunshine Springs were high, because the 15-cm intake dredge was used and increases in pond volumes were relatively small.

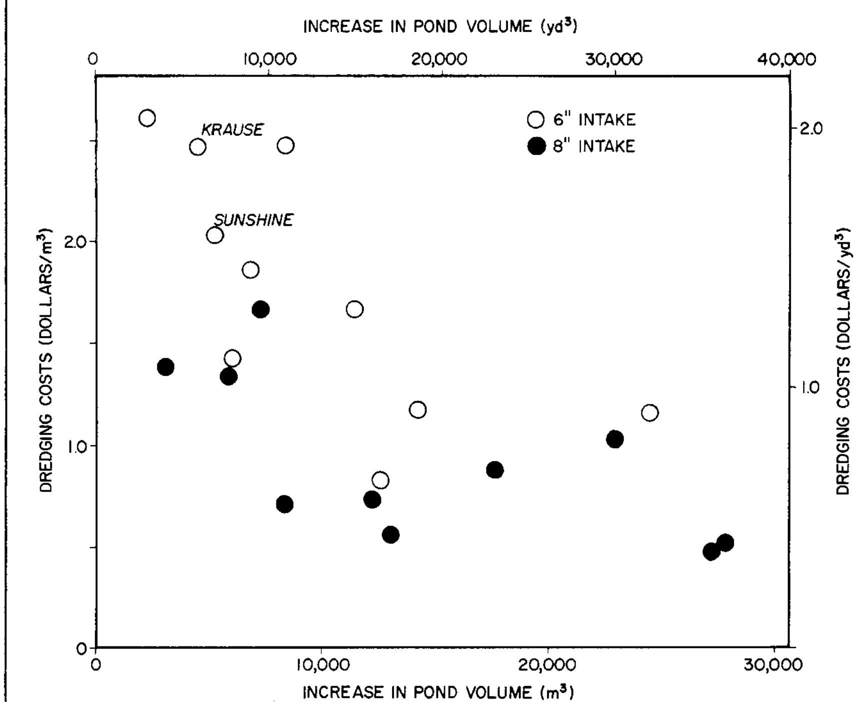


FIGURE 17. *Increase in pond volumes of 20 development projects in relation to unit costs of dredging for state-owned dredges with 6-inch and 8-inch intake pipes. Data points representing Krause and Sunshine Springs labeled K and S.*

Because daily gross expenditures of spring pond fishermen were not measured, we calculated ratios of angler gross expenditures to project costs (AGE/PC) using daily expenditures ranging from \$3 to \$7, based on 1970 dollar values. Andrews et al.(1974) summarized daily expenditures from 13 freshwater fisheries. Based on 1970 values, expenditures/man-day ranged from \$1.44 to \$16.29; the mean was \$6.96 and the median was \$4.85. The national average of daily expenditures for freshwater fishermen in 1970 was \$7.02 (U.S.D.I., Bur. Sport Fish. and Wildl.). We suggest that the average daily expenditure of spring pond fishermen ranged from \$4 to \$6. The average round trip distance traveled by spring pond anglers in 1975 was 62 miles. At \$0.07/mile, transportation costs alone would bring daily expenditures to more than \$4. Purchase of bait and meals would then be added to the total.

Benefits accrued from dredging were taken as the increased number of trips following development. Difference between total number of trips to Krause and Sunshine Springs in 1975 and mean annual number of trips prior to dredging was 267. As dredged ponds gradually fill, their productivities will probably increase, because ponds with intermediate depths support the largest trout populations (Fig. 15). We assumed that productivities of Krause and Sunshine Springs would increase with time and that fishing pressure would increase in proportion to fish productivity. Therefore, we estimated that peak use of Krause and Sunshine Springs would be about 350 trips/year or about 30 percent greater than that measured in 1975.

To calculate a benefit:cost ratio it is necessary to estimate the project's economic life, e. g., the number of years until a pond must be redredged. As noted

TABLE 29. *Economic life and time intervals used to calculate ratios of angler gross expenditures to project costs.*

	Interval									
	1		2		3		4		5	
Economic Life (Years)	Years Covered	No. of Trips/Year	Years Covered	No. of Trips/Year	Years Covered	No. of Trips/Year	Years Covered	No. of Trips/Year	Years Covered	No. of Trips/Year
45	0-5	0-267	6-20	267-350	21-25	350	26-35	350-267	36-45	267-0
55	0-5	0-267	6-20	267-350	21-30	350	31-45	350-267	46-55	267-0
65	0-5	0-267	6-20	267-350	21-35	350	36-55	350-267	56-65	267-0
75	0-5	0-267	6-20	267-350	21-40	350	41-65	350-267	66-75	267-0

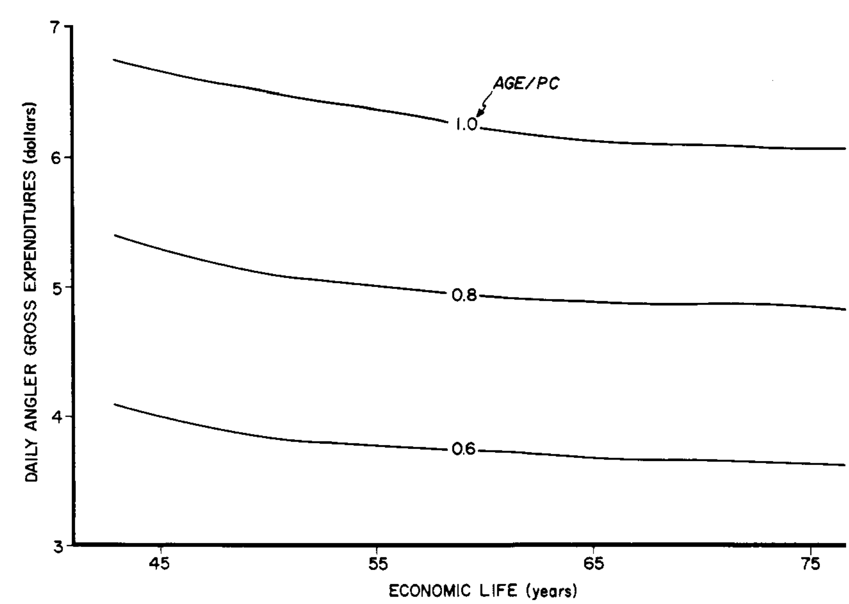


FIGURE 18. *Changes in the ratio of angler gross expenditures to project costs (AGE/PC) at different combinations of economic life of dredging projects and daily gross expenditures by anglers. (Actual dredging costs at Krause and Sunshine Springs ($2.30/m³) and increases in fishing trips shown in Table 29, were used to derive AGE/PC ratios.)*

previously, sedimentation rates in spring ponds may vary considerably and under certain conditions may be quite rapid. Therefore, we have used conservative estimates of dredging project durations. We calculated AGE/PC ratios for 45, 55, 65 and 75 years. Each project duration was divided into two or more intervals to simulate increased fishing pressure to a peak of 350 trips/year and then decreasing pressure to predredging levels (Table 29).

For each project duration, fishing pressure reached peak levels after 20 years. The length of time peak pressure was sustained and the rate at which pressure declined from peak levels to that of 1975 depended upon project duration.

We used a 7-percent interest rate, compounded annually, to compute average annual gross expenditures and average annual costs. Average annual costs are analogous to the annual payment necessary to retire a loan equivalent to project cost. For example, when the economic life of the project was taken as 55 years, annual payment on a loan of $22,600 was $1,621 at a 7-percent interest rate. Expected gross expenditures of anglers were computed for each interval shown in Table 28. Mean number of trips per year during the interval was multiplied by daily expenditure to estimate total annual expenditure. This value was treated as a constant annual annuity capitalized at 7-percent interest, compounded annually. The annuity worth for the interval was then discounted to 1970 values. The sum of present value annuity worth for all intervals of each project duration was amortized for the project duration to arrive at average annual expenditure. Ratios of AGE/PC provide indexes for evaluating economic benefits accrued from dredging.

When dredging of Krause and Sunshine Springs was treated as a single project, AGE/PC ratios at most combinations of economic life and daily expenditures were below 1.0 (Fig. 18). At $5/day, which we suggest as a realistic estimate of daily expenditures, AGE/PC ratios ranged from 0.75 to 0.83 for project durations of 45 to 75 years. Based on the slope of isopleths in Figure 18 with a gross expenditure of $5/day, it does not appear that ratios would approach 1.0, even at an economic life of 100 years. High costs for dredging these ponds and only moderate absolute increases in fishing pressure are responsible for relatively low ratios.

Evaluation of the statewide dredging program should be based on average unit costs, because these costs reflect a wide variety of operating conditions. We recomputed AGE/PC ratios using these average unit costs and the same levels of anticipated use that were used in computations for Krause and Sunshine Springs (Fig. 19). In this instance, AGE/PC ratios were above 1.0 for all project durations when daily expenditures were $4 or more. Thus, if dredging costs at Krause and Sunshine Springs had been similar to the statewide average, economic benefits would have been generally favorable.

We computed a series of AGE/PC ratios because of the uncertainty of daily gross expenditures by anglers and project duration. We suggest 55 years as a conservative, though not unrealistic, estimate of economic life for dredging projects. Even if results of current research suggest 75 or 100 years as more realistic estimates, these increases would have little effect on AGE/PC ratios. For example, at a daily expenditure of $5, the ratio was 0.80 for an economic life of 55 years and 0.83 for a 75-year project duration (Fig. 18). Thus, a 36-percent extension of economic life resulted in only a 4 percent increase in the AGE/PC ratio. The ratios decreased disproportionately because average annual cost changed little ($1,621 to $1,592) when economic life was projected an additional 20 years. If subsequent economic studies of anglers who fish spring ponds or similar waters show that daily expenditures should have been $6 rather than $5 (based on 1970 values) then expected AGE/PC ratios would also be 20 percent higher. Therefore, we suggest that reasonable economic evaluations of dredging projects can still be made when estimates of economic life are conservative. The most important projections will be daily expenditures and increases in use.

We should emphasize that the dredging projects at Krause and Sunshine Springs were not given any special publicity. It is likely that fishing pressure would have increased, if the news media were so utilized. Ponds that are close to heavily traveled roads, have good parking and boat launching facilities, and are relatively large (over 1 ha), tend to receive highest fishing pressure. Many spring pond fishermen prefer angling from boats and do not frequent ponds less than 0.4 ha (about 1 acre) or those that cannot be easily reached by boat. Because of their small size and accessibility, Krause and Sunshine Springs were not heavily fished by boat anglers. If potential dredging projects are to be evaluated on their economic merits, factors affecting fishing pressure should be taken into account.

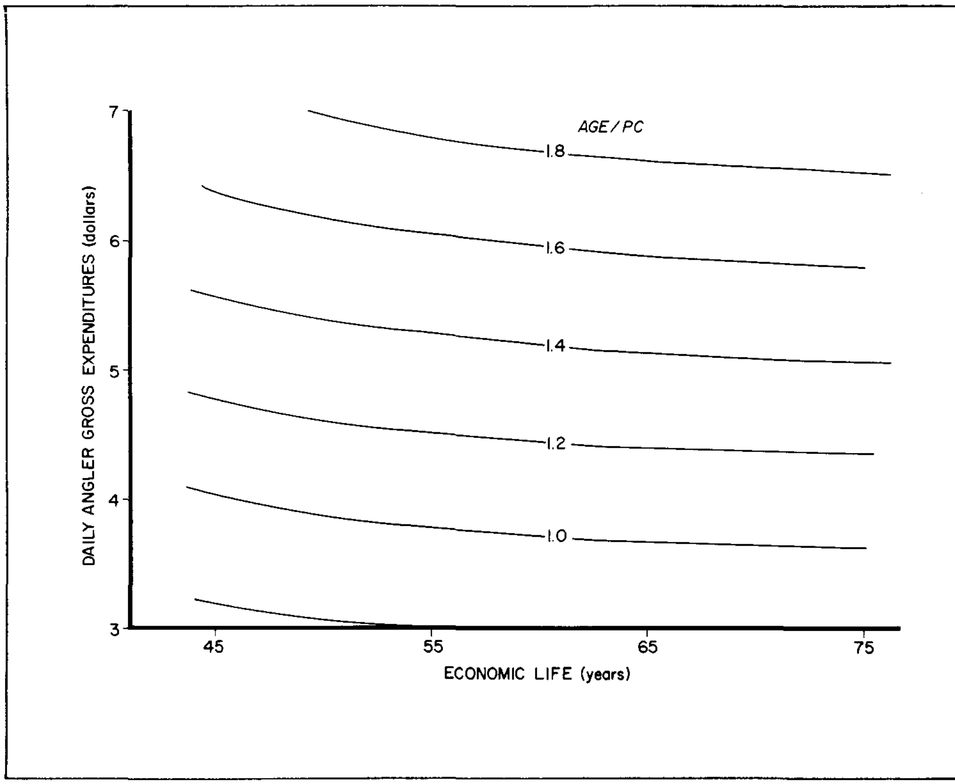


FIGURE 19. *Changes in the ratio of angler gross expenditures to project costs (AGE/PC) at different combinations of economic life of dredging projects and daily gross expenditures by anglers. (Statewide average dredging costs ($1.37/m³) and increases in fishing trips shown in Table 29 were used to calculate AGE/PC ratios.)*

MANAGEMENT CONSIDERATIONS

1. Spring ponds, though often physically discrete, are open-ended systems and trout migrations play an important role in maintaining pond populations. Management plans should be based on the pond-stream complex. Habitat improvements in one segment of this complex may benefit another segment. Conversely, habitat deterioration of one segment may have a deleterious influence on adjoining waters.

2. The optimum depth to dredge spring ponds will depend upon size of the development area. Peak trout productivity occurs in ponds with mean depths of 0.75-1.0 m and maximum depths of 3 m. Some ponds are dredged to mean depths of 1.6 m; however, this procedure may often be the most economical in the long run. Unit costs of dredging ponds less than 0.4 ha (about 1 acre) are usually highest. If these ponds were dredged to mean depths of 0.75-1.0 m, unit costs would be even higher and project duration would be shortened. If the development area is 1 ha or more, dredging to depths of maximum fish productivity seems realistic, because unit costs would not greatly increase.

3. To promote benthic recolonization of dredged spring ponds, we suggest that parts of pond basins, perhaps 5-10 percent, be left unaltered. These areas will maintain diversity in substrate types and provide a refuge for invertebrates. Presumably, recolonization rates will be faster when parts of basins are not disturbed than when entire basins are dredged.

4. Realization of maximum potential trout production in dredged spring ponds will depend upon levels of recruitment. Management options include maintenance of existing spawning areas and development of new ones. Attempts at developing spawning areas have been only partly successful, but present techniques can be effective in certain situations (Carline ms).

There is a continual accumulation of organic materials on spawning areas in ponds. Periodic pumping of these areas can help maintain clean gravel substrates. Brook trout frequently spawn in pond outlets and recruitment from these areas is often vital to pond populations. Pond outlets are usually not subjected to high flows; hence, woody debris frequently accumulates and impounds portions of outlets. Prolonged impoundment can lead to siltation of spawning sites. Periodic maintenance of outlets to insure unimpeded stream flow can be effective.

5. In attempting to summarize economic aspects of dredging, we did not consider sites in which annual stocking of trout was necessary to provide a fishery. Because stocking represents an added annual cost, it must be taken into account when economic considerations will be important in deciding which ponds merit dredging. Although the economics of dredging ponds with natural recruitment appeared favorable, this may not be the case for ponds that must be stocked.

6. Beavers represent a potentially destructive force on spring pond fisheries when they build dams on pond outlets. Dams prevent immigration of trout and may reduce recruitment. Elevation of water levels will greatly increase surface area and heat uptake. As pond levels are raised, ground water inflows will decline, summer water temperatures may increase, and development of trout embryos may be affected by reduced ground water flow. The effects of beaver dams will no doubt vary greatly among ponds, but in general, we suggest that these effects will be deleterious and recommend strict control of beaver activity in spring pond areas.

7. This study was not designed to explore effects of different angling regulations on spring pond fisheries; however, we feel that comments on this problem are warranted. Most spring ponds are heavily fished and exploitation rates may exceed 50 percent in many areas. Age 3 trout sustain the fishery early in the season while Age 2 and even some Age 1 trout are cropped in the latter part of the season. Heavy pressure on public ponds is manifested in a relatively small mean size of harvested trout, about 20 cm (8 inches). As pressure increases, a reduction in the mean size of catch can be anticipated. The prevailing bag limits of 5 trout/day in May and 10 trout/day thereafter, probably have little effect on harvest of wild brook trout populations. Few spring pond fishermen attained bag limits. Even in the Hogelee Springs, where catch rates were among the highest (about 0.9 trout/hr), only 7 percent of the fishermen in May and 9 percent of the fishermen in June-September had a bag limit. If the bag limit in June-September had been 5 rather than 10 trout/day, total catch during the period would have been reduced by 20 percent. Because most of the harvest is taken by anglers who never attain bag limits, a more restrictive bag limit would have little effect on total catch.

The possible effect of increased size limits merits consideration. A 20-cm size limit, for example, would protect most wild trout until age 3. However, gains in survival may be partly or wholly offset by hooking mortality of sublegal fish. Most spring pond fishermen use worms for bait. Therefore, hooking mortality of sublegal trout could be important. Increased use of barbless hooks may help alleviate mortality of sublegal fish.

8. It is apparent from this study that dredging filled-in spring ponds is an effective management program, based on improvements in the fisheries and project costs. We have suggested that in some instances dredging may not be economically sound. However, there appear to be no alternatives to improvement of fisheries in shallow ponds. Unaltered ponds will continue evolving towards a bog-like state, but the quality and quantity of ground water emanating from such areas are not likely to diminish. If shallow spring ponds flow into trout streams, protection from human developments might represent the best management strategy. Our evaluation of dredging projects was in part influenced by current demands for spring pond fishing and economic values assigned to these activities. Demands on trout fishery resources and the willingness of the public to pay for these opportunities may well increase and projects that appear economically unsound at present may become more favorable in the future.

SUMMARY

1. Effects of hydraulic dredging on important physico-chemical and biological features of two spring ponds were studied from 1967 to 1975 with emphases on trout populations and sport fishing yields.

2. Dredging increased pond volumes by factors of 4 to 5 and the predominantly organic sediments were replaced by sediments composed mostly of marl. There was a 41-percent increase in discharge at Sunshine Springs attributable to dredging and no change in discharge at Krause Springs. Increased discharge affected water temperatures of Sunshine outlet, but otherwise, thermal regimes of pond waters were not influenced by dredging. Similarly, there were no changes in concentrations of the common water quality parameters following dredging.

3. Dense beds of *Chara* in Sunshine Springs were eliminated by dredging and within five years *Chara* biomass reached about 10 percent of its predevelopment biomass.

4. Densities of benthic organisms declined sharply during dredging, but recolonization proceeded rapidly. Four to five years after dredging, densities of benthic invertebrates were from 50 to 300 percent greater than predredging levels. Tubificids accounted for most of these increases. Most of the invertebrates that were important trout foods did not reach their former levels; recolonization rates were highest for chironomids and lowest for leeches and snails.

5. There were modest increases in *Daphnia* and *Bosmina* densities following dredging, but increases did not appear to significantly affect total food resources for adult trout.

6. There was only a temporary change in composition of fish communities in dredged ponds. Wild trout comprised the largest proportion of total fish biomass.

7. Trout populations fluctuated greatly prior to dredging, because of large-scale immigrations and emigrations. After dredging, trout that migrated into ponds tended to remain.

8. Mean density and standing crops of brook trout in Krause Springs changed little after dredging, because numbers of trout spawned in the pond did not significantly increase, nor did numbers of immigrants.

9. In Sunshine Springs recruitment increased after dredging, because of added spawning areas for brook trout and increased immigration of brown trout. Five years after dredging, trout biomass was nearly triple that of predredging levels (36 vs. 90 kg/ha). Brown trout accounted for more than half of the biomass increase.

10. Growth rates of trout declined immediately after dredging, but after four years, growth rates were within predredging ranges. Changes in growth rates were associated with fluctuations in the benthos, the primary food of trout.

11. After dredging there were five to tenfold increases in fishing pressure and numbers of trout harvested increased by eightfold. It appeared that both trout populations in the dredged ponds could have sustained even greater fishing pressure without overexploiting them.

12. Growth rates, standing crops, and yield of trout in study ponds were within ranges found for other dredged and unaltered ponds with similar recruitment rates.

13. In ponds with mean depths of less than 0.5 m, living space appeared to be the major factor limiting trout populations. After dredging, the availability of suitable spawning areas and numbers of immigrating trout determined population levels. Four to six years after dredging, ponds with ample spawning areas supported about 100 kg/ha of wild trout.

14. The high production of trout in Wisconsin spring ponds, compared with other small trout lakes, was attributed to high nutrient inputs from ground water, abundant macrophytes, and a rich benthic fauna.

15. Rates of sedimentation appeared related to density of macrophytes, which contributed organic deposits and induced high rates of marl formation.

16. Dredging costs ranged from \$0.52 to \$2.07 to increase pond volumes by 1 m^3. Costs were inversely related to size of the dredged area. Based on actual increases in fishing pressure at Krause and Sunshine Springs and statewide average dredging costs, we concluded the economic results of the projects were generally favorable.

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APPENDIX

I and II: Derived Mean Densities of Benthic Organisms in Krause Springs, 1968-75 (I) and Sunshine Springs, 1967-75 (II).

Mean densities are presented for ten taxa of benthic organisms for each sampling date throughout the study. These tables are available as a supplement from the author or the Wisconsin Department of Natural Resources (c/o Research Coordination Section).

III. Brook and Brown Trout Population Structures in Selected Spring Ponds in Fall*

Pond		Krause	Sunshine		Hogelee #2	Hoglot
Species		Brook	Brook	Brown**	Brook	Brook
Year		1975	1975		1974	1971
Age	0					
	N	772	2,316	26	4,125	1,049
	L.R.	66-117	53-114	79-109	71-117	68-114
	M.L.	91	88	86	91	91
Age	1					
	N	275	710	29	944	1,025
	L.R.	109-173	109-183	157-198	112-175	112-173
	M.L.	142	145	175	145	145
Age	2					
	N	314	247	16	577	714
	L.R.	127-229	173-231	168-295	147-211	157-216
	M.L.	170	188	239	176	183
Age	3					
	N	78[1]	21[1]	39	175	51[1]
	L.R.	183-249	225-269	244-335	188-251	208-250
	M.L.	221	256	267	221	234
Age	4+					
	N			16[2]	52[2]	
	L.R.			256-381	223-345	
	M.L.			305	256	

*Densities (N) are in numbers/ha, and length ranges (L.R.) and mean lengths (M.L.) are in mm.
**lengths averaged for 1974 and 1975
1 includes Age 4 trout
2 includes Age 5 trout

APPENDIX IV. Estimated Density and Biomass of Brook and Brown Trout in Spiegel Springs, 1968-1970.

Date and Species	Trout Density (no./ha) Less than 152 mm	Greater than 152 mm	Total	Grand Total	Trout Biomass (kg/ha) Less than 152 mm	Greater than 152 mm	Total	Grand Total
25 March 1968								
Brook	3,376	2,482	5,858		46.6	142.1	188.7	214.3
Brown	400	217	617	5,475	6.9	18.7	25.6	
14 June 1968								
Brook	1,084	558	1,642	1,790	17.1	47.6	64.7	85.6
Brown	27	121	148		0.8	20.1	20.9	
27 August 1968								
Brook	4,648	1,060	5,708	5,950	30.2	98.5	128.7	173.1
Brown	10	232	242		0.3	44.1	44.4	
15 October 1968								
Brook	568	1,124	1,692	1,791	8.1	103.5	111.6	128.5
Brown	0	99	99		0	16.9	16.9	
7 April 1969								
Brook	1,754	2,487	4,241	4,844	31.6	188.8	220.4	282.6
Brown	72	531	603		1.2	61.0	62.2	
22 July 1969								
Brook	519	936	1,455	1,586	10.4	71.1	81.5	107.0
Brown	10	121	131		0.3	25.2	25.5	
16 October 1969								
Brook	842	1,121	1,963	2,027	12.1	90.1	102.2	112.2
Brown	10	54	64		*	10.0	10.0	
2 April 1970								
Brook	67**	2,132	2,199	2,486	1.2	184.2	185.4	258.6
Brown	20**	267	287		0.4	72.8	73.2	
29 September 1970								
Brook	622**	1,198	1,820	1,953	12.7	84.1	96.8	116.1
Brown	32	101	133		0.3	19.0	19.3	

*less than 0.050
**Densities of smallest size groups underestimated due to small sample size.

APPENDIX V. Estimated Density and Biomass of Trout in Rabe Lake, and Hogelee Springs #1 and #2.

Pond, Date and Species	Trout Density (no./ha.) Less than 152 mm	Greater than 152 mm	Total	Grand Total	Trout Biomass (kg/ha.) Less than 152 mm	Greater than 152 mm	Total	Grand Total
Rabe Lake								
16 April 1973								
Brook	147	202	349	448	3.5	18.8	22.3	65.8
Rainbow*	0	99	99		0	43.5	43.5	
Hogelee Springs #2								
18 September 1974								
Brook	1,814	1,092	2,906	2,906	25.2	72.5	97.7	97.7
24 April 1975								
Brook	2,277	1,459	3,736	3,736	33.7	96.1	129.8	129.8
Hogelee Springs #1								
29 April 1975								
Brook	622	1,269	1,891	1,891	11.3	103.6	114.9	114.9

*Stocked prior to 1973.

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