SOME PHYSICO-CHEMICAL EFFECTS OF BEAVER DAMS UPON MICHIGAN TROUT STREAMS

ARTHUR K. ADAMS

1953

1-D-19

October 5, 1955

TO: D. S. Shetter, In Charge, Hunt Creek Fisheries Experiment Station

FROM: A. S. Hazzard, Director, Institute for Fisheries Research

SUBJECT: Doctoral Thesis, A. K. Adams

I plan to bring with me Art Adams' thesis when I go to the Fish Division Staff Conference at the Rifle River, which as you may have heard will run from October 10 to 12. You might have occasion to drop down during this period and join us in some discussions as you did last fall. On the other hand you may be tied up at Grayling on the hooking experiments. In that case you can pick up the thesis the next time you are at the Rifle.

As you may know, Art included only a part of his voluminous data in the thesis. The balance is here in the form of first draft Institute reports, which because of his illness he has never been able to revise. We are hoping eventually he may be able to condense these reports for use here at the Institute.

ASH:jmm

Report No. 1390

November, 1953

# SOME PHYSICO-CHEMICAL EFFECTS OF BEAVER DAMS UPON MICHIGAN TROUT STREAMS IN THE WATERSMEET AREA

By

Arthur K. Adams

## ABSTRACT

The occupancy of trout streams by beaver has long been a problem to Michigan fishery biologists, several of whom have regarded the physico-chemical effects as harmful to fish populations. My study of this subject centered in Gogebic and Ontonagon counties of the western part of Michigan's Upper Peninsula. The primary research areas were on four streams in the drainage of the Ontonagon River: Middle Branch of the Ontonagon; East Branch of Bluff Creek; McGinty Creek; and Morrison Creek.

Events on and about the study waters from 1948 through 1951 showed beaver-trout ecology to be strikingly fluid. Major observed changes could be classed as catastrophic, long-term, or seasonal. The first often came with violent freshets, such as severe spring break-ups and flash-floods at other times, which washed the dams away, and led to their abandonment by the beaver colonies. However, the animals were usually able to repair structural damage by otter in winter. Long-term evolution included not only the slow

return to normal stream conditions of the reaches formerly occupied by the beaver, but also engendered the deterioration of the thermal, chemical, and other factors previously favorable to trout. Activities of the mammal in maintaining the dams, cutting food, and movements from one site to another were predominantly seasonal.

Thermal and chemical changes of greatest concern to trout management in beaver ponds were diurnal, or of even shorter duration. Maximum-minimum thermometers provided a record of the temperature variations. Chemical determinations of dissolved oxygen, free carbon dioxide, pH, and methyl orange alkalinity indicated several significant differences from the associated, native flowing streams in summer, though not at other seasons of the year. Analyses also included one 24-hour series, and several biochemical-oxygen-demand tests.

Surface water of impoundments became heated in varying amounts, and this warm layer dominated the outlet temperatures for different distances below the dams, depending, for example, on shading, spring flow, and cool-water seepage through the bases of the structures. Ground-water affluents into the ponds themselves provided brook trout with localized cool retreats from intolerable heat, which often progressively increased downstream through either a long flowage or a series of small ponds.

Dissolved oxygen content of the water regularly declined proceeding from the head to the foot of the area in a beaver colony. Whereas the temperature usually did not improve for trout in going over the dams, oxygen content of the water usually rose. Local centers of decomposition in the impoundments were countered by super-saturations of oxygen in aquatic plant beds, but these declined during hours of darkness, according to a 24-hour series of analyses. Biochemical-oxygen-demand tests indicated that the requirements for the substrate are high but those of the water, low. Carbon dioxide and pH analyses provided values following those of the oxygen determinations, but, along with methyl orange alkalinity tests, disclosed little of major significance in trout management.

The chemical conditions in the impoundments unsatisfactory for brook trout seem to encourage competitive fishes such as creek chubs and white suckers to become dominant. Native brook trout proved surprisingly resistant to temperatures above 80°F. for short periods of time in field experiments with natural acclimatization. The heating of the tributaries was more consequential downstream than in the ponds themselves, and often served to warm rather than cool the main streams, which themselves were not as strongly affected by beaver occupancy on the upper or middle reaches.

In forming an overall management program, the biological as well as the thermal and chemical relations must be evaluated. However, discouragement or removal of beaver on marginal trout waters may be warranted when stream survey procedures include an appraisal of beaver-trout relationships.

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"Some physico-chemical effects of beaver dams upon Michigan trout streams in the Watersmeet area."

MAIN POND, MCGINTY CREEK STUDY AREA

Desolation following wash-out, May 25, 1950 (above), and dam restored for the winter, October 31, 1950 (below).

# SOME PHYSICO-CHEMICAL EFFECTS OF BEAVER DAMS UPON MICHIGAN TROUT STREAMS IN THE WATERSMEET AREA

By

Arthur K. Adams

A dissertation submitted in partial fulfillment
of the requirements for the degree of
Doctor of Philosophy in the
University of Michigan
1953

Committee in charge:

Associate Professor Karl F. Lagler, Chairman
Professor William H. Burt
Research Associate Frank F. Hooper
Professor Carl D. LaRue
Associate Professor Frederick H. Test

## ACKNOWLEDGMENTS

This study of the effects of beaver dams upon Michigan trout streams was supported by the Fish Division, Michigan Department of Conservation, to provide the facts demanded for better management of beaver and brook trout, each of which is an important wildlife resource in the northern two-thirds of the state. The assistance was arranged as a research fellowship at the University of Michigan sponsored by the conservation department's Institute for Fisheries Research, which provided office space and field headquarters, necessary equipment and transportation, plus a full-time aide during two season's work in the Upper Peninsula.

The project was directed by Dr. Karl F. Lagler, chairman of the Department of Fisheries in the university's School of Natural Resources, and Dr. Justin W. Leonard, Research Administrator, Michigan Department of Conservation, who was in the Ann Arbor office of the Institute for Fisheries Research before appointment to his present Lansing position in 1951. Each of these men has given more than generously of the valuable time, suggestions, and encouragement needed by a relatively untrained investigator who undertakes an ecological problem of many phases. Its conclusion is due in large part to their assistance.

Among the staff members of the Fish Division's technical section, advice is particularly appreciated from Dr. A. S. Hazzard, the institute's director, on the overall planning of the beaver-trout project; from Dr. F. F. Hooper, who made several worthwhile suggestions on approaches to the limnological investigation; and from Mr. William Christanelli, whose graphic presentations and photographic reproductions contributed so much to the figures of this report.

Valuable aid was provided from time to time by Mr. Ted Monti and the crew of the Watersmeet State Fish Hatchery, Gogebic County, which served as field headquarters for three seasons. The two assistants, Hubert C. Loonsfoot and Howard A. Caron, merit special thanks for bearing with me during fair weather and foul, and for putting in considerable amounts of overtime as demanded by the work at hand.

In reviewing various aspects of beaver management and life history, personnel of the Department of Conservation's Game Division contributed significantly to the project, particularly Mr. David H. Jenkins, who is in charge of the work on fur-bearers and small mammals. Conservation officers, especially Messrs. Leonard Bloomquist and Albert Livingston of Watersmeet, and supervisory personnel of the Field Administration Division in Regions I and II, plus Lansing staff members of the Geological Survey and Lands divisions, were of great help both in the field and in giving advice on technical matters.

Around the University of Michigan campus, the valuable counsel of Dr. Warren W. Chase, professor of wildlife management, is particularly appreciated. Some joint work with Mr. William H. Lawrence, whose doctoral problem concerned the ecology of beaver communities in this state, contributed significantly to the progress and understanding of each of us.

Federal agencies, too, provided assistance in this investigation. A cooperative system of stream gaging around one set of beaver ponds was arranged with District Engineer Sulo Wiitala of the U. S. Geological Survey's Houghton office. Mr. Clarence Johnson, late manager of the Seney National Wildlife Refuge, offered many worthwhile suggestions at the start of this beaver-trout project, as did Mr. J. Clark Salyer, II, Chief, Branch of Wildlife Refuges, Fish and Wildlife Service. Assistance from Ranger Joseph Blake and his staff on the Watersmeet district of the Ottawa National Forest provided valuable contributions at intervals during this study.

Cooperation of anglers, woodsmen, and trappers of the Watersmeet area, particularly Messrs. Herman Tirpe and Paul Kolinsky, yielded more creel census data and background information for the ponds under intensive investigation.

Worthwhile guidance came from Mr. Thomas R. Evans, regional representative of the Wildlife Management Institute at Saint Paul, Minnesota, who had previously worked on the beaver-trout relations of the streams in the Lake

Superior North Shore watershed. The conservation agencies of the two other northern Great Lakes states, Minnesota and Wisconsin, have exchanged information generously with the Michigan Department of Conservation during this project. Ideas suggested by Messrs. Donald Patterson of the Wisconsin Fish Management Division, George Knudsen of the Wisconsin Game Management Division, and Oliver Jarvenpa of the Minnesota Bureau of Fisheries, have strengthened the investigation considerably. Dr. F. E. J. Fry of the Ontario Fisheries Research Laboratory of the Department of Lands and Forests reviewed physico-chemical data.

Identification of several groups of specimens was made by qualified scientists familiar with the materials in question. Dr. G. W. Prescott, Department of Botany, Michigan State College, named several algae; and the higher plants taken from beaver ponds, both aquatics and flooded terrestrials, were identified at the University of Michigan with the help of Dr. Roger McVaugh, Dr. Frederick K. Sparrow, Mr. Keith Wagnon, and Miss Grace E. Blanchard of the botany department.

Finally I want to express my gratitude to several friends, residents of Gamma Alpha house, and my immediate family, particularly my mother and my relatives here in Ann Arbor, who have borne with me from the start to finish of this difficult research project, and whose words of encouragement were vital assists.

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"U.S.-95".

page 38 1st par., 1st line:
replace "U.S.-45" with
"U.S.-95".

# I

## INTRODUCTION

### A. Historical Background

Both beaver (<u>Castor</u> spp.) and trout (<u>Salvelinus</u> and <u>Salmo</u> spp.) are circumpolar in distribution and are interrelated ecologically throughout much of this range. Dam and lodge construction by beaver has been the subject of several significant studies on this continent. Exemplary are the works of Morgan (1868), whose observations were made in Marquette County, Michigan, Martin (1892), Dugmore (1914), and Warren (1927), not to forget the account of almost 60 pages in Seton's "Lives" (1929). Grange (1949) further appraised environmental requirements of the mammal, stressing both water and the preferred food, aspen, which is a succession tree.

The importance of the beaver in the early fur trade of both Canada and the United States is well known. Gregg (1948) described its decline and restoration, attributing the species' ability to survive and recover to "adaptation to life in an aquatic environment, and partially concomitant relative ineffectiveness of predators other than man" (p. 74). The population of this animal in this country was probably at its lowest about 1900; laws over the nation provided total or stringent protection by World War I; and succeeding efforts, including Pittman-Robertson federal aid projects in 27 states during the first ten years of this wildlife restoration program (Rutherford, 1949), have made the animals abundant again in many areas where they had previously been persecuted to extinction. (The Game Division, Michigan Department of Conservation, is to receive a copy of my 45-page literature review, Exploitation, restoration and management of beaver in North America.)

At present the beaver is the second most important fur-bearer of Canada, ranking behind the muskrat (Butler, 1950), as it does in many states of this country. Johnson (1919) told a fine story of Michigan's part in the fur trade, and a year later trapping was prohibited to protect the remaining beavers. However, in 1931 they were again numerous enough for an open season, and in 20 trapping periods since then, the state has produced a harvest of 111,869 of these animals from both peninsulas (Jenkins, 1952).

Although all of the three stream trouts, brook, brown, and rainbow, occur throughout the areas of Michigan occupied by beaver, the brook species (*Salvelinus fontinalis*) predominates in most ponds and immediately connected waters. Hubbs and Lagler (1947) delineated the general range of this fish in North America, and Needham (1938) has given a good description of its life history. Various aspects of the latter are discussed at length in this report as they relate to key limnological conditions which are influenced by beaver. Separate papers will treat food and feeding habits, spawning and migration, and age and growth.

The influences of beaver dams upon trout waters in Michigan were first mentioned by Lowe (1926), and in New York State by Johnson (1922 and 1927). Several stream surveys in the Adirondacks (Hazzard, 1931; Greene, Hunter, and Senning, 1932 and 1934) focussed attention on the problem there, and Hubbs, Greeley, and Tarzwell (1932) commented on the good and bad effects of the beaver on Michigan trout streams, in which this animal was fast becoming a major conservation problem.

In September of 1933 J. Clark Salyer, II, was assigned to investigate the beaver-trout problem in Michigan, and his preliminary report (1935a) was a controversial one, stressing as it did seven detriments to trout fishing rather than six assets, and without the data to support his conclusions. Salyer's recommendations for control of the animals (1935b) led to an extensive program of beaver dam removal throughout the state, the biological effects of which were followed by J. W. Leonard, while the work itself was under the direction of G. W. Bradt. The situation evidently got out of hand, and the operations tapered off at the end of the decade along with other emergency conservation efforts. (A detailed 87-page review, Previous investigations of beaver-trout relations, includes a critical examination of these events, and summarizes literature to 1952 as a Department of Conservation report.)

The problem came to the fore in New York State (Cook, 1940; Bump, 1941), and stimulated stream improvement work along the North Shore of Lake Superior in Minnesota (Evans, 1944). The dam removal program of the thirties still had its repercussions in the Upper Peninsula of Michigan (Carbine, 1944), where further investigation was yet in order. Rasmussen's 1941 report on beaver-trout relations in the swift mountain streams of Utah where the animals were generally beneficial, was hardly applicable to conditions in the northern Lake States.

The Michigan Department of Conservation, recognizing the need for a more intelligent policy of managing these two valuable resources, in September of 1947 intensified its study of the effects of beaver dams upon trout streams by engaging me on a research fellowship at the University of Michigan. A review of the problem (Adams, 1949) and two progress reports (Ibid., 1948 and 1951) precede this summary of the limnological aspects; the material on the strictly biological phases of the investigation is ready for approval as Institute for Fisheries Research reports.

Meanwhile fishery workers elsewhere were concerned with these same matters: Patterson (1950-a and 1951-a) in Wisconsin, Evans (1948) and Hale and Jarvenpa (1950) in

Minnesota, Rupp (1953) in Maine, Reid (1951 and 1952) in New York, and others in western United States. Correspondence and interviews with these men have been mutually profitable in solving the problems of this ecological relationship.

B. <u>The New Michigan Project</u>

The aims of the present study were twofold: the first included a determination, directly and indirectly, of the effects of beaver on waters shared by this fur-bearer and trout; and the second was to establish management procedures for such areas on a sound, factual basis.

(1) Investigational Plan

My plan of attack was to make an intensive study of beaver ponds of known age in one drainage over a three-year period and to follow this with an extensive survey of the state to test conclusions and form broad management recommendations. The extensive survey lost effectiveness because of the interval which elapsed between the time when certain locations were called to my attention, and that of actual inspection.

The ideal period in the field on this project would extend from prior to the opening of the trout fishing season in April through the end of the fall spawning season in November, with a few visits during the winter and the early spring trapping period (Figure 1). Academic work in 1948

Figure 1. Calendar of certain life history relations of beaver (inner circle) and brook trout (outer circle), showing major influences of impoundment (middle circle), adapted from many sources for the Upper Peninsula of Michigan.

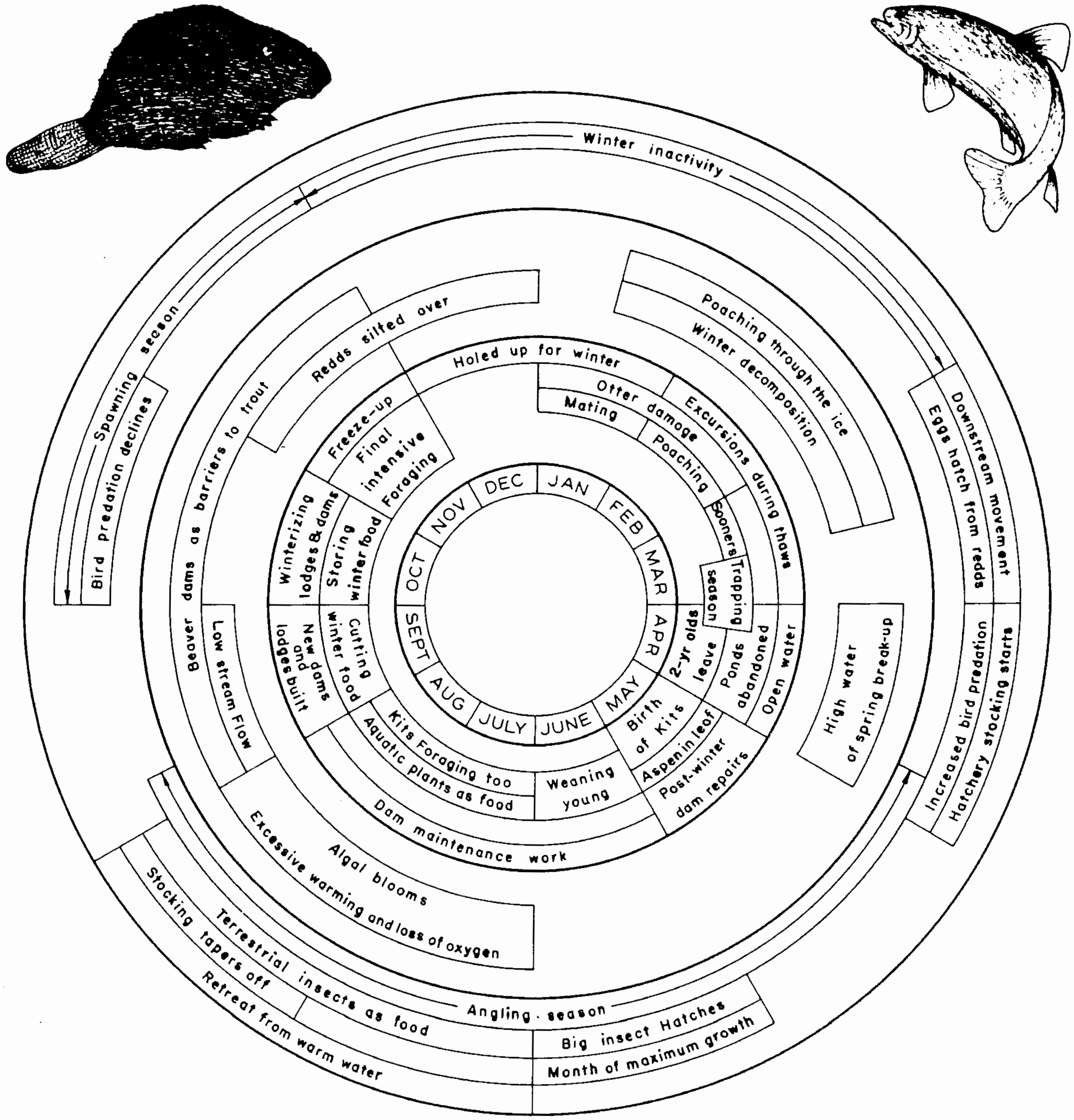

Winter inactivity
Spawning season
Bird predation declines
Beaver dams as barriers to trout
Redds silted over
Poaching through the ice
Winter decomposition
Downstream movement
Eggs hatch from redds
Holed up for winter
Otter damage
Mating
Excursions during thaws
Poaching
Sooners
Trapping season
Freeze-up
Final intensive Foraging
Winterizing lodges & dams
Storing winter food
Cutting winter food
New dams and lodges built
Low stream Flow
DEC
JAN
FEB
MAR
APR
MAY
JUNE
JULY
AUG
SEPT
OCT
NOV
2-yr olds leave
Ponds abandoned
Open water
High water of spring break-up
Increased bird predation
Hatchery stocking starts
Birth of Kits
Aspen in leaf
Post-winter dam repairs
Weaning young
Kits Foraging too
Aquatic plants as food
Dam maintenance work
Algal blooms
Excessive warming and loss of oxygen
Angling season
Terrestrial insects as food
Stocking tapers off
Retreat from warm water
Big insect Hatches
Month of maximum growth

Fig. 1

limited my activities to the three months from mid-June to mid-September, and the first season was of necessity largely an exploratory one. The following two years were devoted primarily to field work from late April until the end of November.

Before the collections of data and materials were started, an operations plan was drawn up late in the spring of 1948, and this was revised each year before leaving Ann Arbor for the Upper Peninsula. A tentative summer season check-list included six of the seven items which turned out to be primary factors (the seventh being the fall spawning activities of brook trout), plus six of the ten aspects which were judged to be of lesser significance at the end of the project. A pond appraisal sheet provided spaces for recording many notable factors of import in evaluating the numerous beaver impoundments visited during this study (page 8).

(2) Scope of Major Investigations

Research centered upon changes of the trout stream habitat caused by beaver occupancy and included study of (a) temperature; (b) water chemistry; (c) fish food organisms and trout feeding habits; (d) fish populations and competitive relations; (e) effects of the dams upon spawning activities; (f) age and growth of brook trout; and (g) yield to the angler (creel census). The first two of the above constitute the major part of this report.

Lake and Stream Survey

INSTITUTE FOR FISHERIES RESEARCH
Division of Fisheries
MICHIGAN DEPARTMENT OF CONSERVATION
Cooperating with the
UNIVERSITY OF MICHIGAN

Beaver Pond Inspection

Date and Time ____________________
Weather ____________________

By ____________________
Other authority ____________________

County: Township T.______ R.______ S.____

Lake or stream: (creek name; trib. to river system, pos. in series) Land ownership:

Stream above dam, avg. width Max. depth

Stream below dam, avg. width Max. depth

Size of pond: Length: Avg. width: Depth, actual or est.:

Adjacent slope: Cover on slope: Beaver food supply:

Dam: Length: Width: Height: Pond elev. above str. level at outlet:

Active or inactive: Age, known or est.: Beaver seen:

Barrier to upstream migration of legal-sized fish:

At present water flow: At higher flow: At lower flow:

Barrier to downstream migration of legal-sized fish:

At present water flow: At higher flow: At lower flow:

Lodges, number and location: Bank dens; number and location:

Color water: Bottom types (above pond, in pond, below pond):

Temperatures, inlet: Dam: Outlet:

Est. flow of water, inlet: Outlet:

Aquatic vegetation species:

Terrestrial vegetation flooded: Percent flooded timber of total pond area:

Fish species and nests, observed or reported:

Fishing reputation in pond: Number of anglers present:

Fish predators, observed or reported:

Other wildlife, observed or reported:

Notes:

Pond mentioned or located by: Cons. Off. for this area:

(a) Temperature Effects.--Many investigators have regarded warming of water during the heat of summer as the limiting ecological factor in streams of marginal value for trout production. Actual figures on thermal tolerances of trout in nature were ascertained along with an appraisal of the related changes in habitat brought about by slow flow, stagnation, and lack of shade in the beaver pond environment.

(b) Water Chemistry.--The requirements of trout for oxygen are rather rigid, and the amount of this element present in water is affected by the photosynthesis of green plants, decaying organic materials, and many other influences which are active in beaver ponds. Also, toxic gases may arise from decomposition on the bottom; however pH, carbon dioxide content, and total alkalinity did not appear significant in the waters studied.

(c) Fish Food Organisms and Trout Feeding Habits.--Unlike the two factors mentioned above, this one is sometimes held to be beneficial to trout in impoundments. The bottom fauna of a stream flowing rapidly over rocks and gravel is quite different from that found in the detritus and quiet water of a beaver pond, and the diet of the trout accordingly changes. Minnows and terrestrial insects are of different import in these two environments, and the species which occur aren't very often the same.

(d) Fish Populations and Competitive Relations.--The numbers of fish present, both trout and other species, were important to this overall problem, where the habitat is much changed from the usual stream conditions. Some kinds were favored by the new environment, but others were at a disadvantage. The development of a technique for conducting fish population studies in beaver ponds posed a considerable problem in itself, and one which is not yet completely solved. In such waters the brook trout are competing with coarse species such as the creek chub (*Semotilus a. atromaculatus*) and white sucker (*Catostomus c. commersoni*); an attempt was made to learn the ratio of these three species, both by numbers and by weight, in this sort of an environment, and to note the changes over a few years. Anglers have had a common experience of good trout fishing in a beaver pond for one or two seasons, following which the catch fell off rapidly, a decline which might well signify changes in the actual fish population present.

(e) Effects of the Dams on Spawning Activities.--Natural reproduction is recognized by many trout stream biologists as the key to angling success over a period of years, particularly on remote waters which are infrequently stocked. The structures erected by the beaver are believed to be harmful to brook trout as barriers to fish swimming upstream to spawn, these individuals then being forced to build their redds in other tributaries, or in a limited amount of suitable gravel at the base of the dam. Nests built in a pond itself may fail to produce fry because of siltation brought on by a lack of current. The magnitude of these effects was little known to fishery biologists, and provided an excellent talking point for sportsmen opposed to the activities of the beaver on Michigan trout streams.

(f) Age and Growth of Brook Trout.--Environmental changes in beaver impoundments tend to warm the water, and increase the overall food production. These in turn should effect an improvement in the growth of the trout, which might mature more rapidly. There has been a marked tendency in recent years to compare the suitability of waters for a species of fish by noting the growth rates in various lakes and streams where it is found. I made such comparisons both (1) before, during, and after beaver occupancy of an area, and (2) between beaver-pond fish and those taken from good trout waters nearby which were not dammed by the furbearer.

(g) Yield to the Angler (Creel Census).--In angling yield studies differences were noted as mentioned at the end of the paragraph above. The return to the fisherman is paramount in fishery management, and its improvement is the aim of many experiments and investigations supported by license fees paid by the sportsmen.

(3) Other Material Considered

The ten following aspects of this problem were not stressed, but some data were obtained relative to each:

(a) Additional life history information on the two species primarily concerned, i.e., beaver and brook trout.

(b) Effects of the beaver as a geologic agent.

(c) Hydrology, flow data, and effects of beaver work on the water table.

(d) Turbidity, ice action, and other physical factors.

(e) Plant succession in and around beaver ponds.

(f) Predation in and around beaver ponds.

(g) Incidence of parasites and disease in beaver-pond trout.

(h) Import of beaver ponds for other fur-bearers and waterfowl.

(i) Beaver-forestry relations.

(j) Comparison of beaver-trout situation in Michigan with that in the Rocky Mountains and elsewhere.

## II

## SELECTION AND DESCRIPTIONS OF THE STUDY REGION AND THE SPECIFIC INVESTIGATIONAL AREAS

As indicated earlier, the sportsmen of the Upper Peninsula had never accepted a large part of Salyer's findings (1935-a) as applicable to their part of the state because most of his field work had been done below the Straits of Mackinac. The opposition of the Northern Michigan Sportsmen's Association to the harvesting of the beaver crop was regarded by conservation administrators as a problem which could be corrected once the facts were available, and that group in recent years had gone on record as favoring the trapping of this fur-bearer.

Thus I was encouraged to conduct a large part of my investigation in the Upper Peninsula on a watershed which was familiar to anglers, and which provided good trout fishing both in beaver ponds and elsewhere. In the spring of 1948 I made a scouting trip through this part of the state to select an area meeting these requirements; among the rivers considered were the Tahquamenon in Luce County, the Escanaba and Yellow Dog in Marquette County, the Paint in Iron County, and the Middle Branch of the Ontonagon in Gogebic County.

The final decision was to concentrate effort in the drainage system of the Ontonagon River with the nearby Paint River tributaries as alternate sites in case of calamities of various sorts on the primary area. A large number of anglers both tourists and local residents, fished the main stream of the Middle Branch of the Ontonagon River, and various beaver ponds on its tributaries. Most of the surrounding timbered land was under the jurisdiction of the federal government in the Ottawa National Forest. Each of these characteristics were valuable to this investigation.

All the study areas chosen were in the Ontonagon River drainage basin of 1,250 square miles; this is the most important Michigan system entering Lake Superior. They were within a 12-mile radius of the field headquarters at the Watersmeet State Fish Hatchery. The streams studied primarily and most intensively were: (1) the Middle Branch of the Ontonagon River five miles west of Watersmeet; (2) the East Branch of Bluff Creek a similar distance north of the town and across the line in Ontonagon County; (3) McGinty Creek five miles northeast of the Hatchery; and (4) Morrison Creek a mile or so east of the field headquarters. The following chart (Table 1) gives an idea of key ecological characteristics of the beaver ponds and the streams.

Secondary study areas were in the Paint River system of Iron County on Cook's Run about 15 miles east of my headquarters, and on Stager Creek between Crystal Falls and

Table 1. Characteristics in 1949 of Beaver-Trout Habitats Studied in the Watersmeet Area.

| Character | Middle Branch, Ontonagon River | Upper Bluff Creek | McGinty Creek | Morrison Creek |
|---|---|---|---|---|
| Surrounding cover | Aspen + stumps | Aspen upland | Aspen + conifers | Lowland conifers |
| Number of dams | Main + 3 aux. | 5 + aux. | 2 + 1 aux. | Main + 2 aux. |
| Age | Fall, 1946 | ? ? | Fall, 1947 | Fall, 1948 |
| Beaver population | 2 ad. + ? kits | 2 adults | 2 adults | 2 ad. + 2 kits |
| Re-occupation | No | Yes | Yes | Yes |
| Extent flooding | Wide | Confined | Fairly wide | Fairly wide |
| Bottom type | Silt and detritus on sand | (same) | (same) | (same) |
| Flooded type | Marsh | Conifers | Marsh | Marsh and conifers |
| Algal growth | None | Heavy | None | Moderate |
| Waterfowl habitat | Good | Good | Good | Excellent |
| Flow of water | Good | Slight | Slight | Fair |
| Spring-fed | ? ? | Yes | Yes | Yes |
| Warming effect | Slight | Fish retreat to spr. holes | Strongest in new pond | Fish retreat to spr. holes |
| Temperature recovery downstr. | No | Yes | Yes | No |
| Oxygen recovery downstream | Yes | Yes | No (?) | Yes |
| Fish food prod. | Good | Fair | Good | Good |
| Fish predators | Abundant | Moderate | Moderate | Abundant |
| Trout stocked | Yes | No | No | Yes |
| Preferred angling style | Flies (upper) | Worms | Flies (upper) | Flies throughout |
| Improved ease of angling | No | Yes | No change | Yes |
| Fishing pressure | Slight | Moderate | Moderate | Heavy |
| Fishing reputation | Fair | Good | Poor | Good |

the Wisconsin state line at the Brule River. The latter location involved a run of more than 50 miles each way, and was visited regularly only during the summer of 1948, the first season of field work. Both Mr. Lawrence and I considered the beaver work on Cook's Run as erratic and/or sporadic, and it too was only under intensive observation for one year. However, these two streams, along with Bush Creek, might have served the purposes of the beaver-trout project just as well as the ponds of the Ontonagon River drainage which were given priority.

In these three western counties, the majority of the precipitation comes during the growing season, but there is also "an exceedingly high snowfall owing to the fact that the winds rising from Lake Superior laden heavily with moisture become chilled and precipitate snow, not only throughout the winter months, but often from early in October to the beginning of May, so that the ground is frequently covered almost continuously for half the year" (Leverett, 1917: p. 25).

Although glacial drift irregularly covers the bed rock, the Pre-Cambrian Formations and their overlay of Paleozoic limestone, shale, and sandstone dominate the physiography. The diverse Pleistocene materials are thick enough over three-fourths of the area to cover or disguise the irregularities of the underlying strata. The origins of this material in the Wisconsin glacial stage have been described by Leverett (1917 and 1929).

In the eastern part of Gogebic County the land is "covered with a sandy, gravelly morainic drift, occasional rock knobs being found in places" (Darlington, 1921: p. 147). Such geology accounts in part for the numerous lakes, some of them in extensive chains, which are a predominant feature of the terrain on each side of the Wisconsin-Michigan State line in the Land o' Lakes-Watersmeet district.

The moderate to heavy growth of timber includes sugar maple, basswood, and American elm on higher ground, plus yellow birth and hemlock. Red and white pine were logged before and after the turn of the century, since which aspen and white birch have invaded these areas. Some balsam is mixed with both hemlock and birch stands; black spruce is more common than the white, especially around the frequent bogs.

However, some parts of this region resemble the jack pine plains of the Lower Peninsula, having a light, dry soil on which grow aspens, young pines (mostly white and jack), pin cherry, white spruce, and balsam fir. The understory of such stands is largely bracken fern, plus the shadbush or juneberry (Amelanchier canadensis).

The U. S. Forest Service recognizes second-growth northern hardwoods as the most predominant type today (Cunningham, 1951). The aspen, usually with northern hardwood or balsam reproduction below, ranks second. The timber economy of this part of the state feeds various primary forest industries but only a small number of secondary ones. However, the area has been for some time an important supplier of raw materials for Wisconsin and lower Michigan saw, veneer, and pulp mills, plus other wood-using plants.

## A. Middle Branch of the Ontonagon River

### (1) The Stream

The Middle Branch of the Ontonagon River has its origin in waters flowing eastward and northward from Lake Damon and Crooked Lake respectively. The two headwater branches passed through several swamp areas above their confluence in Section 21 of Township 45 North, Range 40 West, a short distance above the bridge of highway U.S.-2 (Figure 2). Continuing in a northeasterly direction the river traversed a tract recently occupied by beaver following its use as a landing during logging operations. This marshy section ended at a decaying man-made dam, constructed in the lumbering days, about forty yards above the present Wolf Lake Road bridge.

Downstream there was a stretch of rocks and rapids which, in approximately a third of a mile, changed to a lowland marsh. The primary study area on this stream was located here, less than half a mile above a bridge of the Chicago and Northwestern Railway. Just below this overpass, the outlet from Wolf Lake entered the main stream in

Figure 2. Middle Branch, Ontonagon River, west of Watersmeet, Gogebic County, to U.S.-2 bridge.

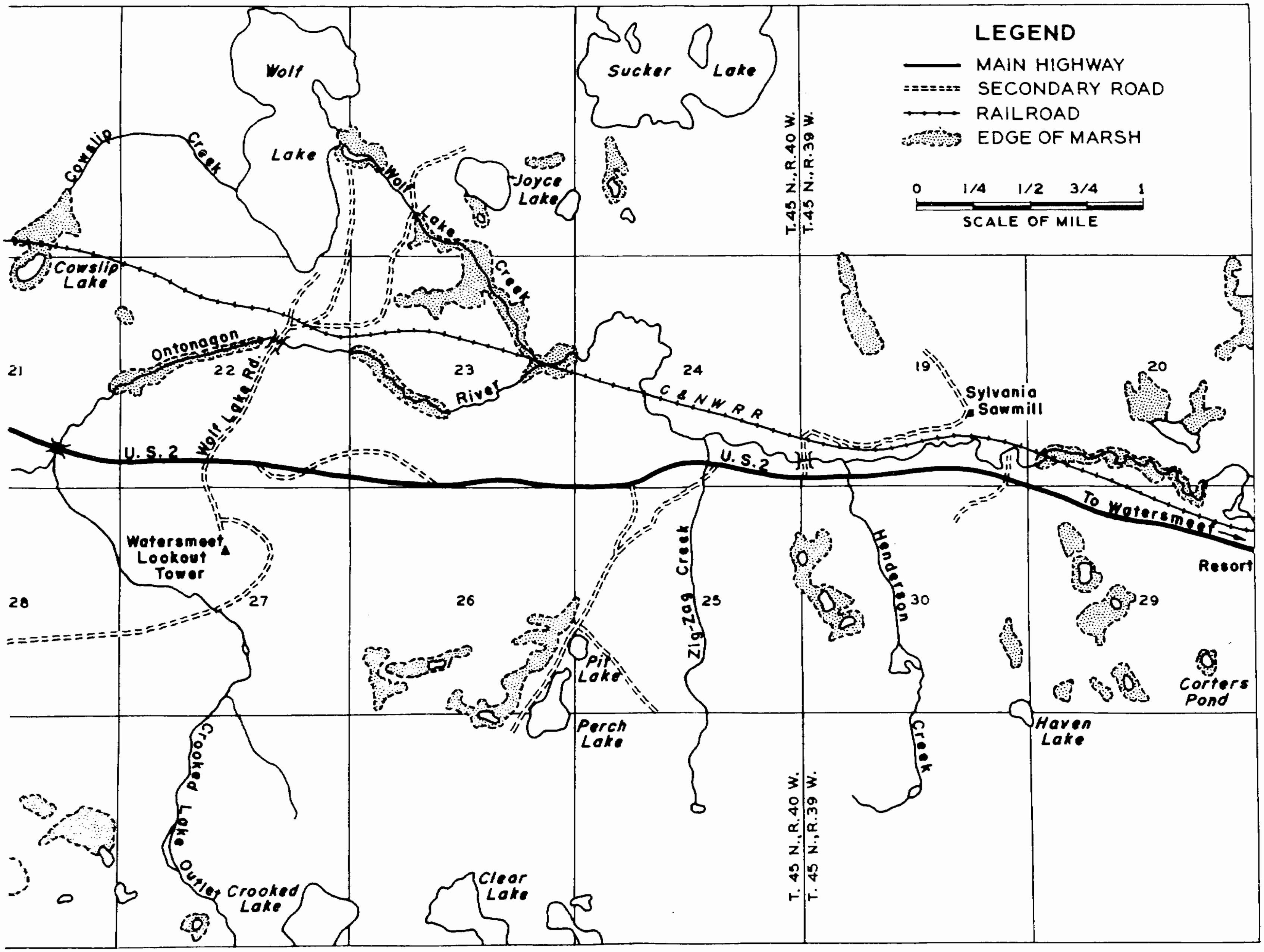

LEGEND
MAIN HIGHWAY
SECONDARY ROAD
RAILROAD
EDGE OF MARSH
0 1/4 1/2 3/4 1
SCALE OF MILE
Wolf Lake
Sucker Lake
Cowslip Creek
Cowslip Lake
Joyce Lake
Wolf Lake Creek
Ontonagon River
Wolf Lake Rd.
C & N W R R
U. S. 2
T. 45 N., R. 40 W.
T. 45 N., R. 39 W.
Sylvania Sawmill
Watersmeet Lookout Tower
To Watersmeet
Resort
Zig-Zag Creek
Henderson Creek
Pit Lake
Perch Lake
Haven Lake
Corters Pond
Crooked Lake Outlet
Crooked Lake
Clear Lake
21
22
23
24
19
20
28
27
26
25
30
29

Fig. 2

another marshy area, which in turn gave way to a stretch where the second-growth timber extended practically to the water's edge. Two tributaries from the south, Zig-Zag and Henderson creeks, joined the river to the west and east respectively of the line between Ranges 39 and 40 West (Sylvania Road bridge).

The main stream continued with a border of brush and timber through Section 19, but with a meadow association bordering the banks in Section 20. This piece of more than two miles was improved for trout by the Michigan Department of Conservation in the summer of 1948 by the addition of about 40 structures. Two thousand willows were planted along the watercourse in May of 1949, and an equal number set out in June, 1951. Meanwhile the high water of the 1950 spring had disclosed some inadequacies in the height of the original work, and 33 structures were capped and/or refaced that summer.

There were alternate areas of wet lowland marsh and swamp, and high wooded banks, as the stream continued eastward to pass through the northern edge of the town of Watersmeet. Here Duck Creek, a sizable tributary, entered from the south just east of the village proper; for creel census analyses and other considerations, this point was selected as the division between (a) the headwaters which were dominated by brook trout, although some brown and rainbow were present, and (b) the lower reaches in which the brown trout appeared to be the most numerous of the three species.

Continuing downstream past the U. S. Forest Service's nursery and district ranger station, the river was about eight yards wide at the Ontonagon Trout Rearing Station, where Sargent's Creek came in from the south. About half a mile below this confluence, the Middle Branch received waters from Bass Lake via Bonifas Creek. The Lake Marion outlet was intermittent, and a mile east of the State Fish Hatchery was the mouth of Morrison Creek, another primary study stream for the beaver-trout investigation.

The rock and gravel bottom present in the Middle Branch below the rearing station was succeeded by one of sand, silt, and detritus by the time the confluence of the Tamarack River was reached six miles to the east. This was about a mile above Burnt Dam (Camp Seven Dam), where the Middle Branch plunged down 20 feet over an old logging dam and a natural rock falls. Above this barrier, warm-water fishes were rare indeed, but below it crappies, bluegills, yellow perch, and others were taken along with the three species of trout. The pan fishes probably came upstream from Bond Falls Reservoir, a storage impoundment of the Copper District Power Company just north of the line in Ontonagon County.

(2) Beaver Occupancy East of Wolf Lake Road

The lower reaches of the Middle Branch of the Ontonagon River were so wide and had such a current that they apparently had never been dammed successfully by the beaver. However, there were several bank colonies of this animal, and others were active along all the tributaries. The beaver dam which I found farthest downstream was west of Watersmeet in Section 21 of Township 45 North, Range 39 West (Figure 3). Here the stream was about eight yards wide, and in October of 1949 the animals had impounded a 2.5-foot head of water. The structure was weak, and had no auxiliary dam below to brace it. This was the first attempt by the beaver so far downstream in 18 years, according to one of the local residents; and the dam washed out in the severe spring break-up of 1950, although some of the individuals may have been trapped earlier in the year.

The animals were active in Section 20 when this stretch was being improved by the Department of Conservation in August of 1948. However, they were unsuccessful in damming the river, which here too was about 25 feet wide. Numerous bank dens were evident, but there was no sign of any old sodden dams; I concluded at this time that the beaver were unable to impound water in these reaches, although they often tried. In mid-spring of 1949 a stream improvement crew of the conservation department reported beaver damage to some of their structures in this section. To be sure, both these animals and the deer had found the willow shoots to their liking. Halfway through the series of improvements a small dam had been attempted, utilizing the two parts of a double-wing deflector as a base of

Figure 3. The farthest downstream beaver dam (above) and lodge (below) on the Middle Branch of the Ontonagon River, October 27, 1949.

Fig. 3

operations. Over the line in Section 21 there was a broken structure of the beaver which had evidently held more than two feet of water, in the face of a strong current, for at least a short time.

On May 5, 1949, an airplane cruise disclosed no active or functional dams on the Middle Branch of the Ontonagon River below the Chicago and Northwestern Railway bridge in Section 23 of Township 45 North, Range 40 West. Evidently there was a successful effort by the animals a short distance downstream from the bridge in the fall of 1950, judging from the water backed up in this vicinity on November 22nd. The beaver food supply on the stream margins in the two miles below this area was sparse, except for a few places where aspen stands were close to the water's edge. In the opposite direction towards the study area the river was 15 to 20 feet wide and had a few deep holes. Sand and gravel made up most of the bottom, with frequent snags and rocks. There was some peat, detritus, and muck inshore; and several beds of Ranunculus sp. and Sparganium sp. were present in the stream bed. Each side the Middle Branch was bordered by lowland brush, particularly tag alders, with aspen and mixed hardwood on the upland.

Just above this half-mile stretch was a sizable beaver pond about 0.4 mile north of the highway. I first saw this in late July of 1947, but it had probably been impounded the preceding autumn. The dam had a length of about 75 feet, and was eight feet wide at the base in the old stream channel (Figure 4). It rose to a height of five feet, and the pond elevation above the stream level at the outlet was four feet in late June of 1948. The structure then was rather instable, and mudded only at the south end; standing on it in spots I could depress the level as much as eight inches.

As an indication of beaver occupancy in previous years, a meadow about half a mile long extended upstream from the structure in a northwesterly direction and covered about 25 acres of lowland marsh, streamside tag alders, and large, scattered elm trees. The U. S. Forest Service's 1947 timber survey map classified the north border as dominated by aspen and paper birch saplings of low to medium density; continuing westward and upstream from the meadow, this shore was covered with a spruce-fir complex low-stocked in the pole stage. On the other side of the river, the meadow, and the Middle Branch itself for a quarter mile above this area, was bordered by northern hardwood saplings of poor density. Further to the south were pole-sized aspen and paper birch in medium to good stands.

The flooded area in 1948 and 1949 ranged between 12 and 15 acres, a figure which varied according to the beaver's activities in maintaining the dam. For the most part the shoreline corresponded with the break from lowland marsh to

Figure 4. Main dam, Middle Branch of the Ontonagon River study area.

Fall, October 4, 1949

Winter, February 7, 1949

Spring, May 3, 1949

Summer, August 20, 1948

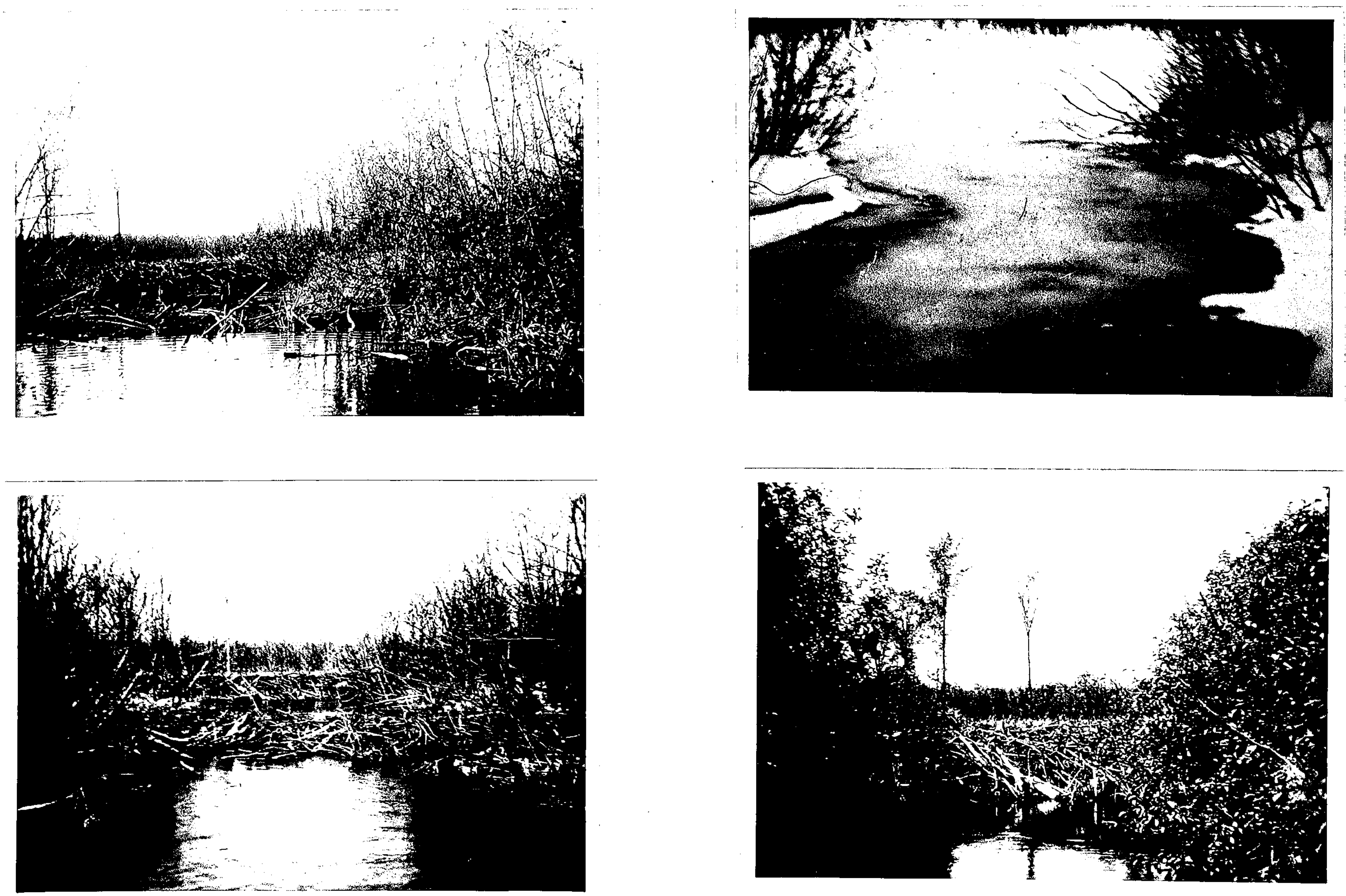


Fig. 4

upland aspen, birch, and cherry, except for the edge of the water at the head end of the pond. The margin was almost regular, but for extended bays at each end of the dam, and for the few intermittent water courses which entered the pond.

The depth of the impoundment may be considered in two categories: (a) the old stream channel, which meandered back and forth through the meadow, with some stretches more than five feet deep, and (b) the flooded marsh, which was a maximum of two feet deep at the submerged edge of the river. The original creek bottom was largely sand, with several gravel beds; each of these types became buried under the typical beaver pond sediment: a mixture of silt, organic detritus, and fibrous peat of varying thickness. The marsh was growing almost entirely on a bottom of the last sort above, and typical situations of both depth and substrate resulted from various beaver workings: channels, canals, food piles, and excavations for building material.

A few conifers and elms were apparently killed by the partial inundation, but most of the latter continued to thrive in as much as 21 inches of water; the same was true for tolerant shrubs such as dogwood and elderberry. However, the streamside tag alder was soon drowned out; both it and the willows in the middle reaches were utilized by the beaver. The marsh growth included several species of Scirpus and Juncus, but for the most part consisted of numerous grasses, some growing in tussocks.

The Middle Branch here was popular among stream fishermen until the advent of the recent beaver dam. Not only did they express concern over the changes brought by the animals, but habitual beaver-pond anglers too were not satisfied. For the latter the stream was too deep to wade, and the close edge of the marsh to the original channel made boating impractical, with the result that this area was fished much less than might be anticipated.

As mentioned above, the study area some five miles west of Watersmeet was about as far downstream as the beaver could successfully maintain a dam. Current velocity readings taken with a Bentzel velocity tube on May 26, 1949, showed 7.10 c.f.s. at the head of the main pond, and a flow of 7.41 c.f.s. below it. The river was not shaded here, and consequences of this, with such a large volume of flow compared to that of the tributaries, should have presented a contrasting situation. The overall oxygen effects were also regarded as different from those on smaller creeks, and with a minimum of flooded timber the pH might well be less affected than in the usual Michigan beaver pond.

Unique among the study streams, the Middle Branch of the Ontonagon contained all three species of trout; there were also creek chubs and white suckers. However, more information on the competitive relations of trout with such coarse species came from Morrison Creek than from this stream. An opportunity was available for comparing two distinct associations of fishes and food organisms, those of the channel and those of the meadow. The dam itself was regarded as a barrier to upstream movement of fish and seemed well suited for special study of this phase in the project. Among the three original primary areas, the one on the Middle Branch of the Ontonagon was the oldest from the standpoint of beaver occupancy. From the above, the many possible differences in beaver-trout relations as contrasted to those on a small feeder creek were paramount in the choice of this area for intensive investigation. However, the depth of water and difficulty in maneuvering any sort of craft made some desirable field operations very difficult during the project.

(3) Beaver Occupancy West of Wolf Lake Road

During an airplane cruise of May 10, 1949, I saw no active beaver dams between the primary study area and the U.S.-2 bridge. Above the large lowland meadow was a rocky stretch of river about half a mile long, towards the upper part of which was the Wolf Lake Road bridge (Figure 2). There was a sizable drop in this section, the head of which was marked by an old logging dam. The river was mostly rapids, and there were few pools of any size; it was well-shaded, and for most of the way the forest canopy extended completely over the waters.

In scouting the stream for prospective spawning areas of brook trout the following September, a dam flooding about five acres of marsh was found close by the site of an old logging landing at the end of an abandoned railway spur. It was about three feet high, with half this head of water, which was cascading over an un-mudded crest. There was a lodge half way up the pond on the southeast shore, and the beaver food supply appeared to be favorable. An abandoned dam an eighth of a mile downstream was holding six inches of water a foot below its crest, and a short ways below was the site of a much larger one which had been dynamited in the 1930's.

Although this pond was not under intensive study, it was visited from time to time. The gap from the spring break-up of 1950 was three yards wide, and at the end of May the water level was two feet below the crest. Meanwhile the small abandoned dam referred to above, which was 30 yards upstream from the logging one, was being rebuilt to hold 18 inches of water. The animals next shifted operations to the blown-out dam, which by May 29th had a 15-inch head a foot below its original height.

Three weeks later this pond was full, with two feet of water. The dam itself at the channel was well constructed of sticks and grass, but had a minimum of mud. Late in July there was still no sign of a lodge under construction here, although the water level had been raised another six inches, and the beaver evidently were going to spend the winter despite the poor food supply. The pond was rather narrow, but could have flooded the extensive marsh upstream;

it was the warming under such circumstances which had occasioned the blasting of the previous beaver dam at this site. Unlike the pond on the other side of the Wolf Lake Road bridge, this area continued to provide good angling for the trout fishermen.

Below this main dam, and ten yards upstream from the old logging structure, was an auxiliary one holding but a foot of water, which was pouring over its whole length. By late November, the main backwaters extended past the old beaver lodge in the pond above, but no new house was visible under the snow cover. The animals probably stayed through the winter, but there was no beaver work at all in this area when it was cruised on July 28, 1951. All the dams had been broken at the channel in the severe spring break-up, which was even more violent than that of the previous year.

Above the U.S.-2 highway bridge the river divided into three forks, which had the character of tributary streams, and were not considered in this study. There was beaver work on each of these creeks, of which the largest was the Crooked Lake outlet. Five inactive dams a short distance above the highway were cruised in June of 1948, and on July 7th of that year a series equal in number upstream and south of the U. S. Forest Service's Watersmeet lookout tower was warming the water to 71-73°F. However, this influence appeared to be counteracted by the cooler water of other streams and spring seepages before this flow reached the actual confluence at which the Middle Branch of the Ontonagon River had its start.

## B. East Branch of Bluff Creek

### (1) The Stream

The East Branch of Bluff Creek had its origin in spring seepages from cedar swamps in the northernmost section tier of Gogebic County, whence it flowed in a northwesterly direction (Figure 5). Midway to its mouth, in Section 34, it received a small branch from the west of highway U.S.-45, and some flow still from a large beaver pond in Section 27, an area which mostly fed Matheson Creek to the north. The east and west branches of Bluff Creek had their confluence in Section 28 a short distance west of the highway to form the main stream, which flowed towards the north through two large ponds in Section 21, and was joined by Paulding (Spring) Creek two miles downstream. Roselawn Creek also entered from the east, within a mile of the U. S. Forest Service's Paulding lookout tower, and the Bluff itself joined Sucker Creek two and a half miles further on, its mouth being about half a mile west of Craigsmere. The Sucker in turn was a tributary of the South Branch of the Ontonagon River.

The stretch of the East Branch of Bluff Creek which I studied in detail was the upper three miles most of which

Figure 5. East Branch, Bluff Creek, Gogebic and Ontonagon counties, north of Watersmeet.

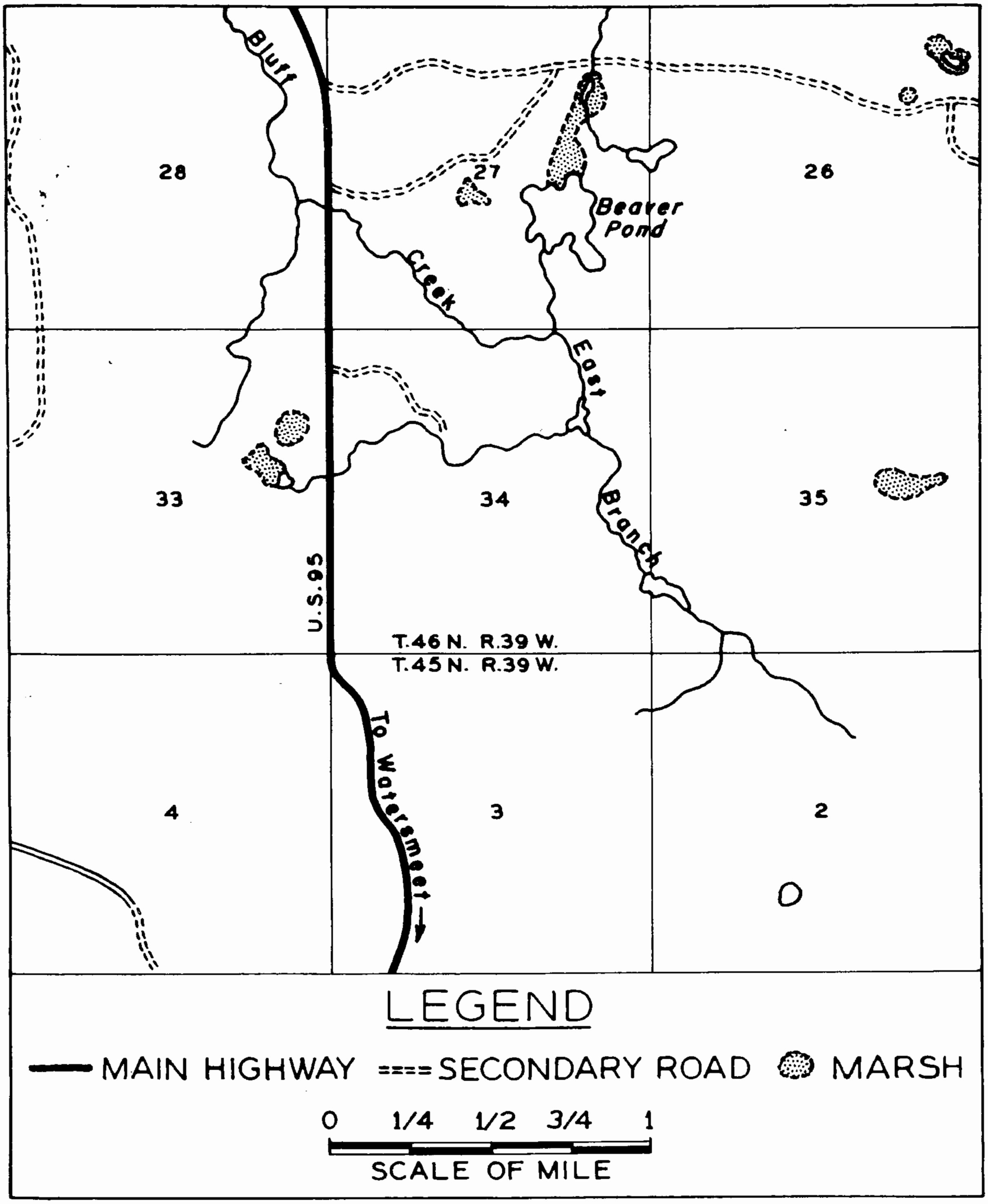

Bluff
Creek
East
Branch
Beaver
Pond
28
27
26
33
34
35
4
3
2
U.S.95
T.46 N. R.39 W.
T.45 N. R.39 W.
To Watersmeet
LEGEND
MAIN HIGHWAY
SECONDARY ROAD
MARSH
0
1/4
1/2
3/4
1
SCALE OF MILE

Fig. 5

lay to the east of U. S. highway 45. No flow measurements were taken on the creek, the volume of which was not subject to any marked fluctuations. It had a moderate gradient, coursing as it did between two ridges of high land; and this steepness of fall accounted for several differences from the overall conclusions based on findings from other study areas. In this section, Bluff Creek was usually colorless but became slightly brown following heavy rains. The stream was three feet wide and quite shallow in the upper two forks. The bottom here was predominantly sand and gravel, with a few short stretches of rock. The first two materials also formed the substrate by the highway bridge, where very few rocks were present; here the stream was about eight feet wide and averaged about two feet in depth.

(2) Beaver Occupancy

The character of the Bluff had been much changed by frequent periods of beaver activity, which were generally regarded by the local residents as beneficial to trout fishing. Anglers living nearby have fished the ponds for about a 15-year period, including the times when their efforts were spent on backwaters of abandoned dams and the stream channels proper after the original structures had been dynamited. There has been no stream improvement work on this creek, but such a project appears desirable to speed the waters through some of the old flowages, and to hasten recovery from beaver occupancy.

Before considering the East Branch of the Bluff itself, some comments on its tributaries appear in order. The large beaver pond in Section 27 formerly drained entirely southward to Bluff Creek, but recently the flowage extended much further to the north, and the most of its excess water went to Matheson Creek instead. This flooded area was a swampy thicket of alders and conifers, in which the beaver were active during the summer of 1948. This was reputedly not trout water, but it appeared to be ideal black duck habitat.

Also entering the East Branch in Section 34 was an intermittent water course in a deep ravine through a jack pine plantation. Here, with some aspen on the slope and more of this preferred beaver food accessible upstream via a canal system, the animals built a dam in the fall of 1947, blocking the gorge with a structure about nine feet high. The area showed signs of recent activity when visited on March 24, 1950, but later that spring the dam was washed out with the severe break-up. All that remained of the pond the following autumn was a small pool about two feet deep, and the wet weather provided only a feeble flow early in November.

The tributary running eastward across Section 34 had its origin in a marsh west of the highway, at which beaver have frequently been a nuisance by damming the culvert. The source of this branch is a warm-water rather than a spring area, although some flow of the latter sort did enter it on the east side of the highway. Trout were present here only in the lower half of the rill where there was no beaver work except for the junction with the East Branch of the Bluff, which was flooded by the backwaters of a dam on the creek proper.

The stream below the pond just cited was bordered by lowland brush, particularly tag alder, with a fair stand of second-growth hardwoods and white pine on the slopes, atop which the jack pine plantations extended to either side on the upland. The creek itself was very well shaded and aerated in this stretch of a mile or so east of the highway, factors in large responsible for the recovery of the water from upstream beaver-pond physico-chemical conditions not favorable to brook trout.

The dam of the lowermost impoundment on the study section of the Bluff was 40 yards long, with many angles, and the backwater extended a similar distance upstream. It had been built in 1942 or 1943, and was sodded with various herbs; some shrubs were also growing on its crest in the summer of 1948. There was an active lodge about three-quarters of the way up the pond and just west of the main channel. The pond elevation above the stream level at the outlet was about three feet, and the impoundment itself was heavily silted. The beaver's supply of aspen here was low indeed, and a fair amount of cherry was evidently being cut for food as well as for building material.

On the opening day of the 1949 trout fishing season, the water level in the lower impoundment on the East Branch of Bluff Creek was down a foot and a half from the dam crest. Closer inspection revealed that the dam had been undermined at the old stream channel, where there was a hole six feet deep, over which the framework of the structure was still intact. Nevertheless this area was still kept under observation to note its fate following a fairly long period of beaver occupancy. Above the lower main pond there was a transport one. Its dam was about 20 yards longer than that downstream, although it held only a foot of water. The two evidently had been built at the same time and flooded about three acres of alder and marsh grass between them. Each of these areas had provided good brook trout fishing, particularly early in the spring seasons. After the beaver had left the ponds, experienced anglers still took limit catches from time to time, mostly from the recently-flooded bottoms of the tributary entering from the west (Figure 6).

The East Branch above the ponds just described averaged six feet wide and two feet deep. Upstream the creek was well-confined to its former channel and flowed through a series of beaver meadows between the ridges. Here several dams had been dynamited by the C. C. C. crews in the thirties, and again, more recently (1944?), by a conservation officer. Some lowland brush was growing along the banks, but the cover was mostly grasses, which here

Figure 6. Lower ponds, East Branch of Bluff Creek, looking northward from point between main stream and tributary from the west.

Summer, August 2, 1948

Winter, March 24, 1950



Abandoned, May 3, 1949

Vegetated, July 14, 1949

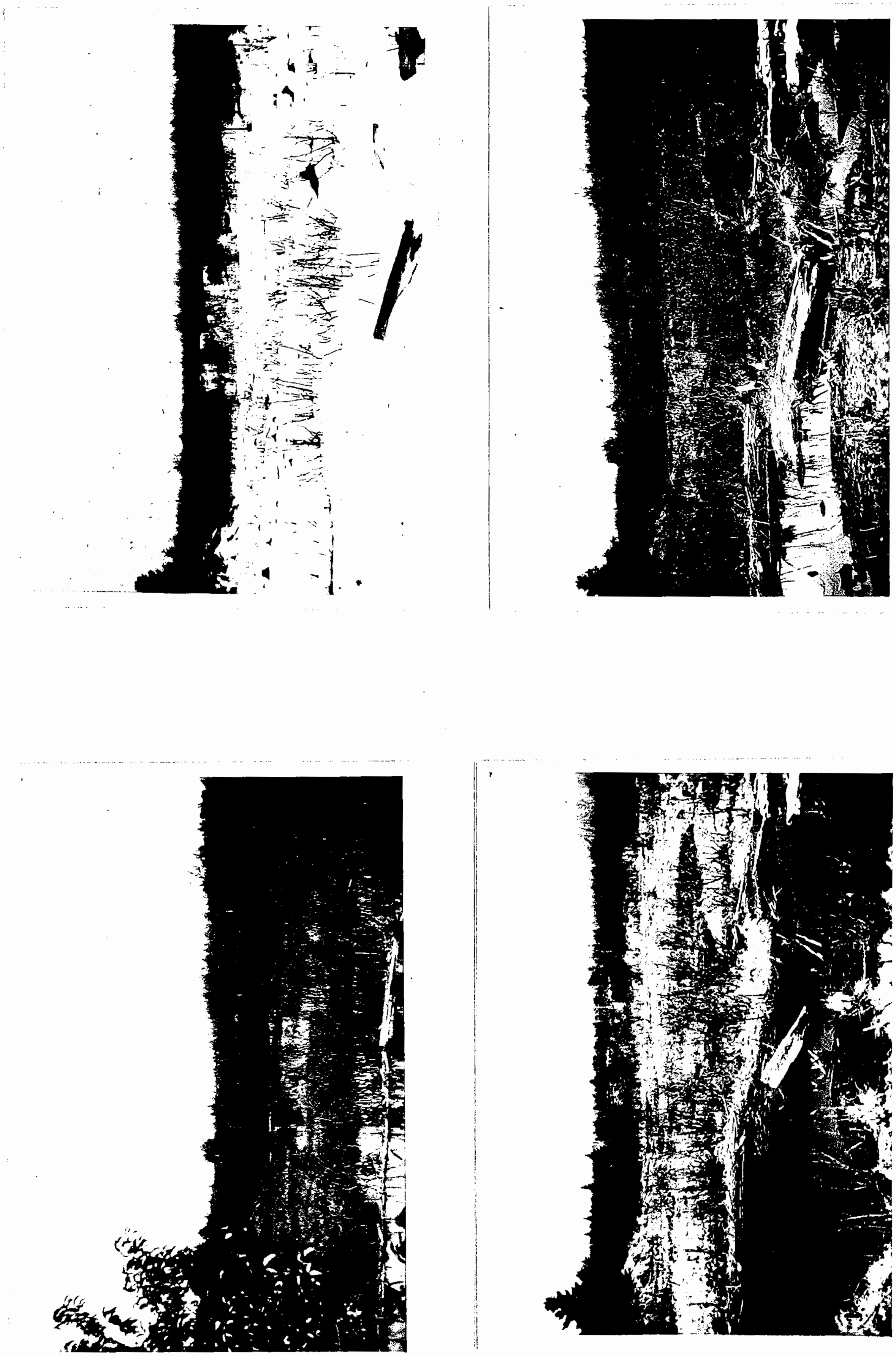


Fig. 6

extended onto the surrounding upland with its old burnt-over stumps of pine and frequent young cherry trees. Beyond a neighboring jack pine plantation, northern hardwoods bordered the stream course on the west, whereas the other side was timbered with young aspen, birch, and cherry, which adjoined a stand of black spruce. The creek through these upper reaches was well-supplied with spring water, some of which seeped down from the swamps to the east.

Slightly more than half a mile above the lower dams in the study section there was a series of six beaver ponds in various stages of use and decay, from one to another of which the animals shifted their major concern. These too were first visited on July 27, 1948, and the next season became a primary investigational area, replacing Stager Creek in Iron County. Following one season of field work it became apparent that the situation here was much different from that prevailing on the three other streams under observation in the vicinity of Watersmeet. However, because of the portage of equipment for more than a mile, these ponds were visited only once a week during the period of intensive research. Several avenues of study here were not followed through as thoroughly as they would have been had the ponds been more accessible.

The first dam of the upper series, a small structure facilitating the transport of food and building materials for beavers, was about eight feet long, and well-based in the west stream bank. It was sporadically extended into the alder swamp to the east to interrupt the overflow there. The pond was widest about ten yards upstream from a sodded, dynamited dam which dated back to the 1930's. The marsh was tending toward a warm-water association, with scattered patches of cattail among the predominant grasses and bulrushes.

Forty yards above the foregoing dam, with the stream back in its channel, was the second structure of the series, which had flooded an acre or so of thick alder brush and scattered conifers. This too was an auxiliary area and contained no lodge, although the dam was three feet high and could have provided sufficient depth for underwater entrances. In late August of 1948 the beaver were cutting aspen on the east shore; the next year the dam was again kept in good repair, but in 1950 the water level was sometimes as much as a foot below its crest.

The third dam of the group (indicated in Figure 5 as impounding the water) was some four feet high and solidly constructed of peeled aspen bolts for the most part. It was apparently five or six years old by 1948, and the flooded alder and scattered conifers had been dead for some time. Most of these trees had toppled over to decay, but many balsam and spruce remained either upright or tilted at weird angles (Figure 7). About 20 yards in from the north end of this 75-yard dam, and ten yards upstream, there was a sizable lodge in which the beaver continued to

Figure 7. Views looking northward from hill south of Dam IV, upper ponds, East Branch of Bluff Creek.

Pond III, Spring, May 16, 1949

Dam IV, Spring, May 16, 1949

Pond III, Winter, March 24, 1950

Dam IV, Winter, March 24, 1950

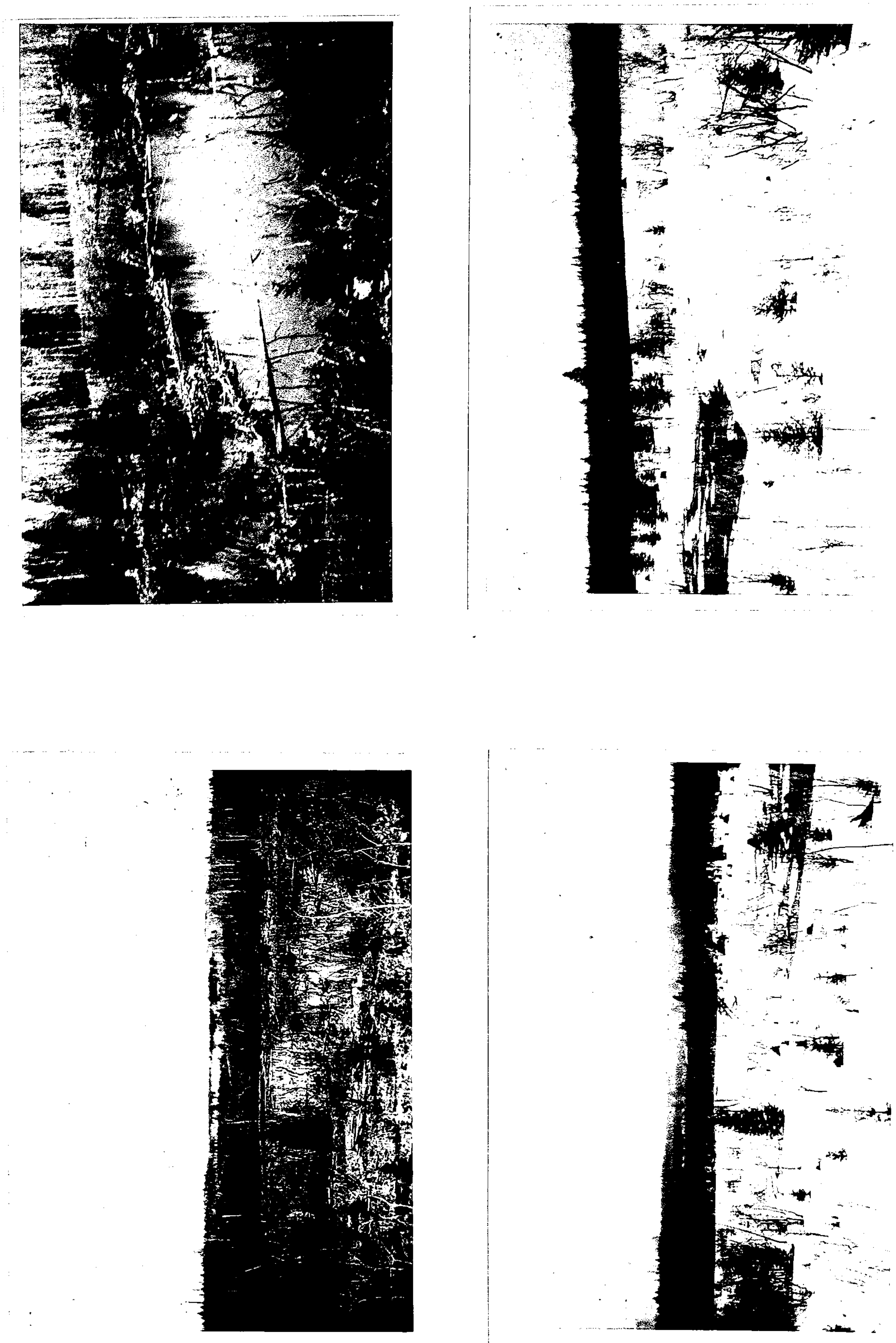


Fig. 7

have an interest throughout my study. The aspen to the east had been cut back about 50 yards, but the animals continued to use it.

Dam IV was at the head of the two-acre flooding just described, and it was an older one about two-thirds as long as the next one downstream (Figure 7). A decaying lodge on the east shore a short distance upstream had long been abandoned by the beaver, but the sodden dam itself was kept in good shape for transport and usually held a 1.5-foot head during two years of inspections. This pond with few trees amounted to little more than an acre and was fed by several springs from its western slope.

The fifth dam, three or four years old in 1948, was then in poor condition and holding but a foot of water. The 1.5-acre pond contained many flooded conifers and a fair number of drowned alders. A narrow piece of spruce-fir timber extended down a ravine to its edge from the east to break the upland cover of aspen and paper birch. The presence of the latter two tree species may have encouraged the beaver to spend the two winters of 1949-50, 1950-51 with this as the home pond. The dam had a four-foot head during these periods of occupancy, and the old lodge about 15 yards upstream became a veritable castle of peeled aspen.

The beaver had passed the cold weather of 1948-1949 in a lodge on the west shore of Pond VI; this was for a long time the uppermost impoundment of the series, i.e., until a seventh auxiliary dam was built in the fall of 1950 on the east fork. The sixth one was new in 1947, but fell into disrepair off and on during my study years. Even on August 20, 1948, the top of the 3.5-foot dam was nine inches above the water level of the pond, and its 30-odd yards already sodding in with jewelweed. Here too there was a good food supply of aspen on each slope, and in the "v" between the two branches of the stream. Almost the entire flooded stand of alder was already dead in the summer of 1948. The drowned conifers also died quickly, except for one magnificent white pine about ten yards above the dam which remained green until the next field season. The pond fluctuated in area more than the others downstream, however, it was always between one and two acres in size, including a large flooded marsh unfit for brook trout.

It is perhaps appropriate at this stage to consider the six upper ponds on the East Branch of Bluff Creek as a group, for they were the home of the same beaver colony and similar in many respects. The whole flooded area was less than ten acres in maximum extent. The ponds were confined within two ridges rather than extending laterally over a wide expanse. The shorelines were regular, closely following the contours of the upland, with few real bays aside from those created by the beaver in their foraging activities.

The original bottom type of these reaches of the stream had been sand and gravel, to which no proportions can be assigned. On top of this was an overlay of silt, detritus, flocculent and pulpy peat; the deposit varied in depth from nothing in spots kept clear by the beaver to an unappraised value in flooded seepage areas. Some of the ponds' substrate was clay similar to the surrounding upland, particularly where the slope was abrupt. There were also a few large rocks in the impoundments.

As usual in beaver ponds, the deepest spots were either just above the dams themselves, or at the plunge holes by the lodges. No systematic soundings were taken, but estimates of seven feet are reasonable for the vicinities of Lodges III and V when the heads of these impoundments were highest. The water upstream from the dams averaged close to five feet near the original channels by the five larger structures, decreasing to either side except where a canal came in; customarily the beaver had dredged these areas to get mud for their building activities.

The extent of flooded timber has already been mentioned for each pond. Few higher aquatic plants except duckweed flourished in the upper four sizable impoundments, whereas the lower two seemed to be approaching warm-water marshes. The growth of algae during the two summers of intensive observations will be discussed as it effected chemical changes, particularly the oxygen content of the water.

The Bluff Creek study area, remote as it was, had maintained a reputation for good fishing over more than a decade. The angling here for the most part was strictly with worms and a small pole cut on the spot, although Pond III and small portions of others could have been fished with flies. This was definitely brook trout water, and there were evidently no creek chubs present. Angling, here, despite the treacherous footing, was improved over that which would have prevailed with overhanging tag alders from bank to bank, but cooperative volunteer creel census did not materialize.

Invertebrate food for brook trout was abundant in the upper Bluff Creek ponds, but the numerous minnows did not appear to be utilized greatly. The six beaver impoundments in a close series must have been some hindrance to the spawning of trout in this stream. Fortunately there were suitable areas both above and below, but the barrier effects of the dams were not thoroughly understood.

The physico-chemical components of beaver ponds on the Bluff were noteworthy because of the spring water affluents, the stream gradient, algae-growth, and possible downstream recovery from detrimental thermal conditions in the impoundments themselves. The expected increase in acidity following the flooding of conifers was not apparent behind these dams, perhaps because the timber had been drowned out some time prior to this study. The changes with time in these six beaver ponds may well have been slow for the most part, but they further demonstrated the relative fluidity of ecological history in such habitats.

## C. McGinty (McGinnity) Creek

### (1) The Stream

This run had its headwaters in Plains Lake (Township 45 North, Range 38 West, Section 13) which was in a muskeg bog lying close to the Iron County line (Figure 8). It flowed northward through two more boggy areas which had been influenced by beaver occupancy over the years. The lowland stream margins here were timbered mostly with black spruce and white cedar. Swinging then in a northwesterly direction, the creek passed through a large alder swamp and entered a marsh, at the foot of which the beaver dam built late in 1947 formed one of the primary study areas. Similar cover extending northward was not permanently flooded, however. Below this series of ponds was a meadow from a large man-made impoundment dating back to the harvest of the pine, and downstream the creek again flowed through alder-thickets, with scattered grass openings, on each side of the U. S. Forest Service's Trout Creek Truck Trail. Its direction remained the same crossing over into Ontonagon County; it veered first northward, then westward, to enter the Middle Branch of the Ontonagon in Section 28 of Township 46 North, Range 38 West.

The creek just above its confluence with the river was about six feet wide, and had a rock and gravel bottom. Here the waters were in a deep valley and were well-shaded by alders and willows. Having a gradient of about 15 percent,

Figure 8. McGinty Creek, Gogebic County, east of Watersmeet.

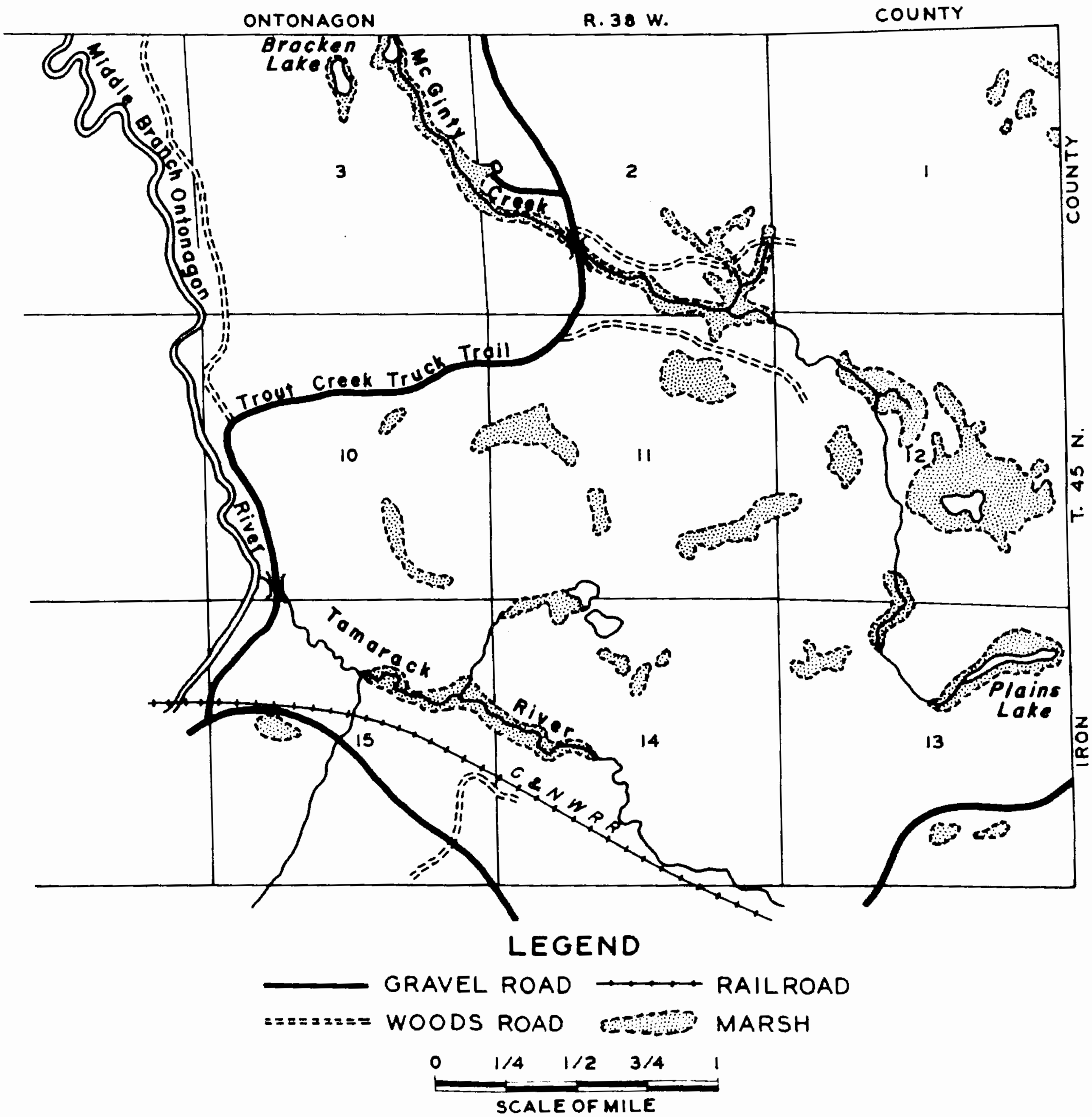

ONTONAGON
R. 38 W.
COUNTY
COUNTY
T. 45 N.
IRON
Bracken Lake
McGinty Creek
Middle Branch Ontonagon River
Trout Creek Truck Trail
Tamarack River
Plains Lake
C&NWRR
1
2
3
10
11
12
13
14
15
LEGEND
GRAVEL ROAD
RAILROAD
WOODS ROAD
MARSH
0 1/4 1/2 3/4 1
SCALE OF MILE

Fig. 8

the stream evidently recovered oxygen in this region, and its temperature was much improved over the beaver-pond conditions of its middle reaches. A large amount of drift-wood provided good fish cover above the mouth of the creek, near which there were a few old beaver-cut stumps, but no sign of any recent dams on August 23, 1949.

(2) Beaver Occupancy

In Section 3 there was an active colony of the animals visible from the air in May of 1949. A year later this pond was reported to be providing good trout fishing, but I never visited it.

The study area itself may be considered as the stretch of McGinty Creek extending upstream from the Trout Creek Truck Trail bridge in Section 2 to the end of the marsh area practically on the section line to the east. In these reaches the creek was flowing through a valley with little fall, and its volume above and below the beaver pond series on May 24, 1949 amounted to 2.66 and 2.29 cubic feet per second respectively. This was the brownest water of the four streams under intensive investigation, a condition which stemmed from the several bogs and coniferous swamps which fed it.

The creek below the ponds and near the middle of its course ranged from four to six feet in width and had holes as much as two feet deep. The bottom here was pre-dominantly sand and gravel, with numerous stretches of rock or peat. Upstream from the beaver colony it was wider but shallower on the average and flowed through alder and coniferous swamp.

The dense cover of alder below, and the soft sand and peat bottom above the ponds, made these areas difficult to fish except for hardy "plunkers" using worms rather than flies. On the other hand the open beaver flowages were suitable for both styles of angling, provided the fisherman kept his footing along the old stream channel banks. Most of the brook trout taken below the ponds were sublegal fish, and on a small feeder creek such as this there had been no improvement work except for the dam removal activities of the Civilian Conservation Corps in the 1930's. The grassy marsh and alder swamp bottom of the creek gave way on either side to poor stands of pole-sized aspen and paper birch on the surrounding uplands, and a spruce-fir sapling association in low areas adjacent to the run.

The most downstream beaver work in this area took place during the latter part of the study when a colony was established less than a hundred yards above the road in August of 1950; at such a late date it was not practical to consider this occupancy in the investigation, but a brief description follows. An auxiliary dam with a 1.5-foot head had its backwaters confined to the original stream channel; this was 30 yards upstream from the bridge, and its effects extended an equal distance beyond to the main dam, around the south part of which there was a considerable overflow.

This structure itself held three feet of water, and appeared to have a good foundation despite its weak crest. It was solid only at the north end, where moss, rocks, and sod from the adjacent bank were the principal materials. This home dam was about 40 yards long with many bends, and on the north shore a quarter of the way up the pond there was a lodge in which the animals spent the winter of 1950-51. The lower third of the impoundment was practically all tag alder thicket, which was varied upstream with nettles, Spiraea, willow, and a meadow association about 15 yards wide. The upper third of the approximate acre which was flooded consisted only of heightened water in the original stream channel.

About a quarter-mile above the Trout Creek Truck Trail bridge (Figure 8) was the old logging pond dam built of rocks and timbers. Its upper side had become well-sodden over the years, and the crest had grown up with lowland brush similar to that downstream. The creek proper flowed through a break in this structure about ten yards from its north end, where there was a drop of three or four feet over the rocks. This confined channel was a natural place for the beaver to take advantage of the man-made improvements already at hand, which they did in July of 1949 to reflood the meadow area upstream. Their work on the structure was erratic, and no lodge was built on this pond, which served both as a foraging spot for favored marsh plants and for the transport of aspen logged on the south slope.

The history of the flooding, aside from the beaver element, was complicated by its use during the logging days, and it was not as intensively studied as was the home pond upstream. However, it was the site of several ecological observations and the source of some interesting physicochemical data. The original stream bottom which was bared through most of this area, was sand; and the sharp banks were marshy peat, much of which had been deposited since the turn of the century.

Twenty yards upstream from the head of this six-to eight-acre man-made meadow was an old sodded beaver dam with a break in it on each side of a small island which divided the old channel of the creek. Here too the animals improved on the situation by blocking both of these, and adding to the height of the old structure with small alder and willow stock topped by grass and mud (Figure 9). However, the beaver maintained a 2.5-foot head of water through the summer of 1948 and into 1949, when they commenced reactivating the man-made block downstream. The small pond, which was only about half an acre, was an auxiliary one, serving for food transport as well as for bracing the main dam 40 yards upstream. It was primarily a flooded meadow association, with some alders and willows at the head end and along the margins. The bottom was silt and detritus atop the original sand, in which an excavation directly dehind the structure was five feet deep.

Figure 9. Auxiliary dam, McGinty Creek study area.

Spring, May 12, 1949

Summer, July 13, 1949

High water, May 4, 1950

Fig. 9

At the head end of the supporting pond was the home dam, which had been built in the fall of 1947. It stretched about 30 yards between two pieces of stable highland, and was six to eight feet wide at the base. When first visited on June 26, 1948, it was holding slightly more than two feet of water, but this head increased during the period of beaver occupancy. The structure had a good foundation, although the crest was flimsy at times when the animals were raising it by adding grass, mud, and/or small sticks.

The pond itself was divided into two ecological units by an old sodden dam a short distance above the current one. This had been dynamited at its north end in 1934, although the pond then was reportedly providing excellent fishing. It had grown up to nettles, vines, and shrubbery in the interim, but eventually was overtopped by the colony under study, which built a fair-sized lodge at the end of it on the edge of the stream channel (Figure 10).

The lower part of the pond was less than an acre, the curving shorelines of which followed the upland contours; the upper reaches totalled five or six acres, and extended southward in a large bay or marsh and to the north along a tributary stream. The original bottom of the recently flooded area had been clay and sand, which soon took on an overlay of detritus, silt, and peat. The maximum water depth of about five feet was immediately above the dam, and at the holes by the lodge and upstream in the former channel.

Figure 10. Beaver lodge, McGinty Creek study area, looking southward.

Fall, October 12, 1950

Winter, February 18, 1949

Spring, May 12, 1949

Fig. 10

Figure 10 (continued). Beaver lodge, McGinty Creek study area, looking southward.

Summer, July 13, 1949

Low water, May 11, 1950

High water, May 4, 1950

Fig. 10

The substrate had probably been sand and gravel at one time, and there were still some exposed areas of this sort which had been kept clear by the animals' activities. The marsh grasses were growing on rich peat, which was being added to the old stream bottom along with other typical beaver-pond deposits, including wood of various sorts.

The new dam flooded a thicket of alder and Spiraea, plus a few tamaracks, but no timber of any consequence (Frontispiece). Aquatic plants were slowly developing in the lower part of the flowage, particularly duckweeds and smartweed. The upper reaches were entirely a meadow association, with willows and alder at the edges (Figure 11). The marsh was dominated by bulrushes and grasses; there were some goldenrod, mints, and other annuals along the margins. The stream channel, especially just behind the blown-out dam, had quite a growth of smartweed, and patches of duckweeds scattered throughout, but not enough to hinder fishing.

This impoundment was subject to only slight angling pressure during the study. No really sizable brook trout were noted in fishermen's creels, but most of them took at least a few of the favored game species. A majority of the anglers favored the meadow area for fishing over the alder reaches at the lower end and were successful both with flies and worms.

There was a substantial population of minnows in this pond, including the creek chub, but common white suckers

Figure 11. Upper reaches of main pond, McGinty Creek study area, looking eastward from south end of blown-out beaver dams.

Fall, September 19, 1949

Spring, April 29, 1949

Summer, July 26, 1948

Dry, May 11, 1950

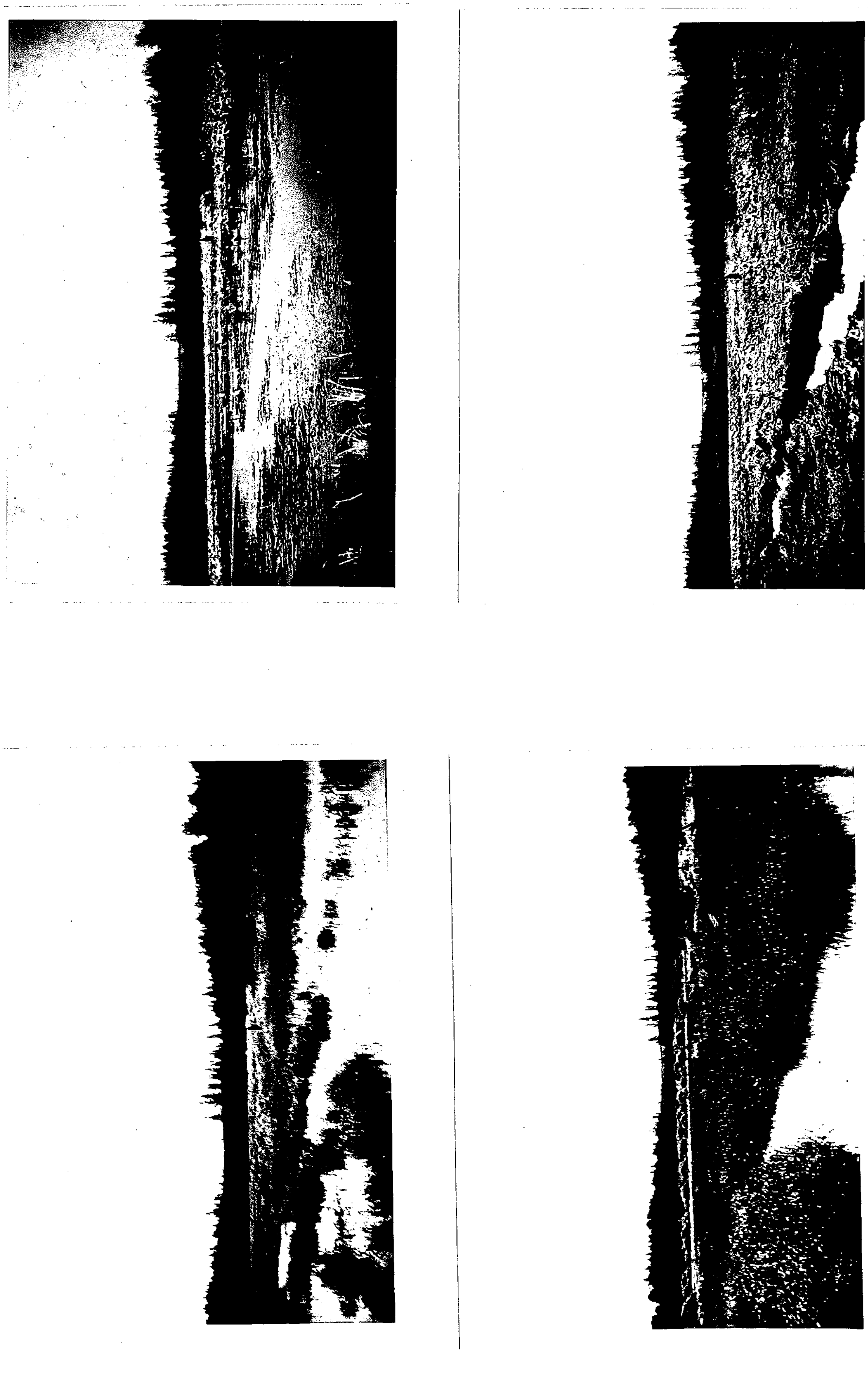


Fig. 11

were rare. The brook trout had plenty of food, both minnows and insects, but the numbers failed to hold their own. Suitable spawning territory for the trout species immediately above and below the ponds was limited, and the competing fishes seemed better able to withstand the unfavorable physico-chemical conditions of the summer. As expected at the start of the study on McGinty Creek, oxygen depletions were frequent. Rises in stream temperature were not, however, as severe as anticipated because numerous springs in the pond, counteracted the warming of the surface water. There was a definite thermal stratification in the impoundment, and seepage through lower interstices of the dam particularly during the first two summers, cooled the outlet below the temperature of the flow over the top of the structure.

In the past beaver had been active in the upper reaches of McGinty Creek and had effected some changes in the bog areas along the stream in Sections12 and 13. I visited these on August 1, 1949, when there was no current activity, and the men who were guiding me could supply little past history. By November 8th there were three small dams in the more northerly of these two stretches, but this occupancy was not followed further because of the limited food supply. No ponds had been visible during an air cruise of the extreme headwaters the preceding May. However, a U. S. Forest Service employee had enjoyed good fishing on a beaver flowage in these parts ten years previously.

### D. Morrison Creek

#### (1) The Stream

This creek had its source in a large spring east of Marion Lake in the southwest quarter of Section 28, Township 45 North, Range 38 West (Figure 12). The origin was surrounded by a poorly-stocked stand of aspen and paper birch over a spruce-fir association, each of which was only sapling size. Along the stream's northward course of 2.5 miles to the Middle Branch of the Ontonagon River, it received water from several other such flows, including those flooded by the present main upper pond, two of which were noteworthy both for their size and as trout habitat. The only tributary of any consequence was a brook running in a southwesterly direction across Section 21.

The supply of spring water in the Morrison drainage was doubtless affected by logging activities; hardwood and spruce were both taken in the World War I period, the pine having been lumbered a few decades previously. Although lowland brush bordered the stream proper in its upper reaches, to the west there was a sizable stand of hemlock sawtimber; a cedar-spruce swamp association was more prevalent on the opposite side than the northern hardwoods or aspen-birch in the highlands.

Figure 12. Morrison Creek, Gogebic County, east of Watersmeet.

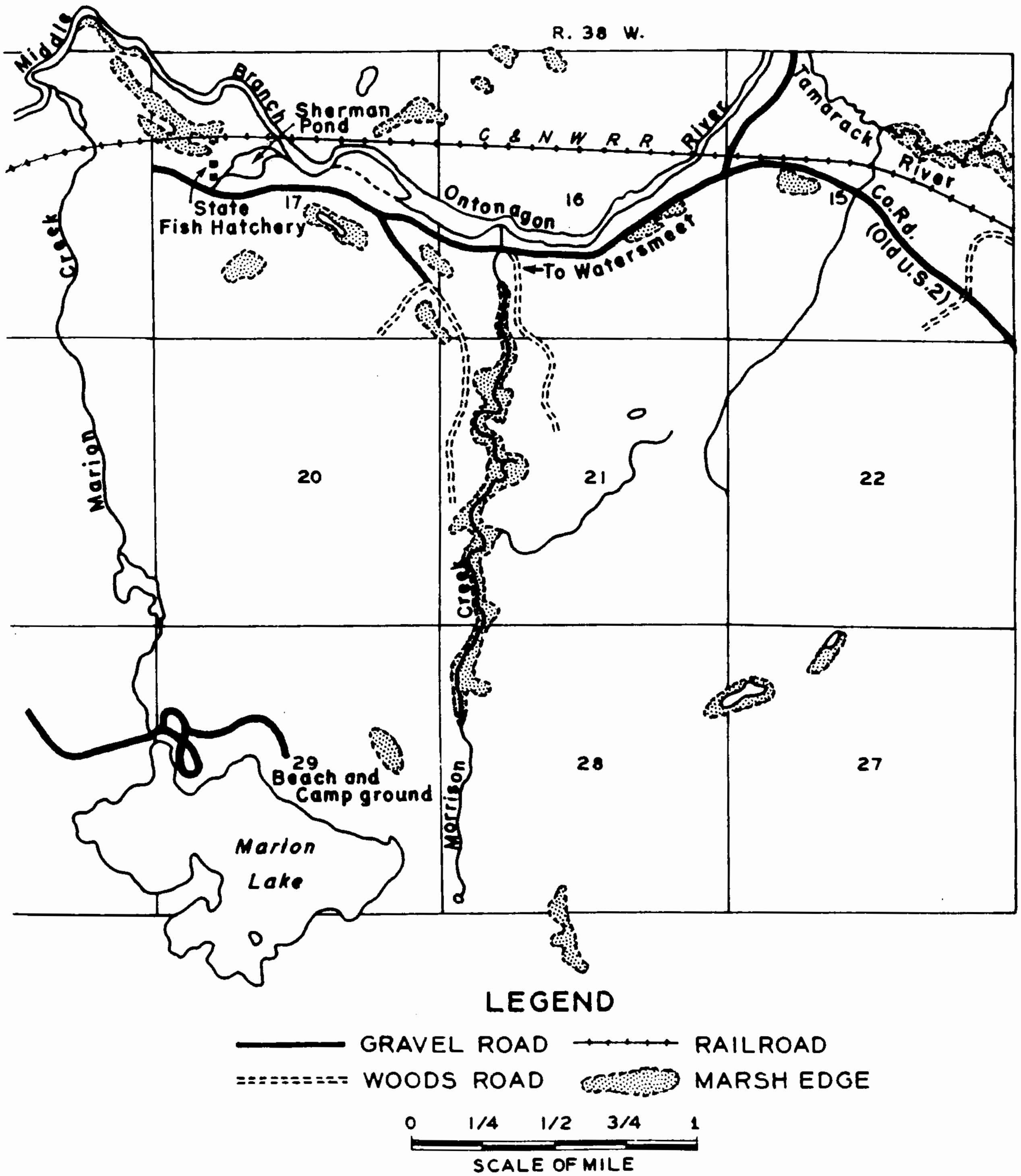

R. 38 W.
Middle Branch Ontonagon River
Sherman Pond
C & N W R R
Tamarack River
State Fish Hatchery
Co. Rd. (Old U.S. 2)
To Watersmeet
Marion Creek
Morrison Creek
Marion Lake
Beach and Camp ground
T. 45 N.
16
17
15
20
21
22
29
28
27
LEGEND
GRAVEL ROAD
RAILROAD
WOODS ROAD
MARSH EDGE
0 1/4 1/2 3/4 1
SCALE OF MILE

Fig. 12

Two-thirds of a mile from its origin the stream entered a marsh area which showed the effects of beaver occupancy over the past 30 years or so. This dense tangle of long-dead conifers and streamside alder, in which grass tussocks and other wetland vegetation were flourishing, continued northward for a mile and a half, with a width varying according to the surrounding terrain. Fully three-quarters of this old marsh was the result of beaver activity at one or the other of two narrow necks along the Morrison in the northwest quarter of Section 21, the history of which will be traced later.

To the east of the foregoing streamside ecological association were patches of lowland brush, black spruce, either with white cedar or alone, and only in the most upstream quarter mile did the northern hardwoods come down all the way to the marginal marsh. The white cedar-black spruce stands of the western edge first gave way downstream to pole-sized hardwoods; then, beyond a small clearing, to aspen and paper birch over a spruce-fir understory. Sapling and pole stands of poplar were broken by plantations of red and jack pine along the downstream reaches to the typical lowland brush of alders and willows bordering the Middle Branch of the Ontonagon River at the creek mouth in Section 16.

There were no falls along Morrison Creek, and nothing that could be called a stretch of rapids; however, there were a few gravel riffles in the lowermost quarter-mile, which had remained free of the beaver's immediate influences. The water course ran through low terrain for its entire length, breaking a narrow valley across the uplands just south of the river; even here however, there was no prominent stream gradient. The volume of water was quite steady throughout the summer months, but was accentuated during such periods as the spring break-up, and the severe rains of both this season and of the autumn. Bentzel velocity tube measurements taken May 25, 1949 showed flows of 2.18, 2.77 and 2.78 cubic feet per second at three stations, each of which was located within three-quarters of a mile from the creek mouth. Despite the headwater swamps, the stream was brownish in color only during the spells of heavy run-off as mentioned above.

The periods of beaver occupancy have had pronounced effects on three aspects of this stream; depth, width, and bottom types. The first was influenced by dam-removal operations, excavations around them and at the lodges, siltation, and stock-pilings of food. Second, ponding typically widened the lotic area to give backwaters which extended perpendicular to the stream channel just above some dam sites. Third, original stream bottom types were variously buried under silt, detritus, and peat deposits, or scoured out at the plunge basins formed by overflows tumbling over the dams.

The undisturbed headwaters were four to six feet wide, and to two feet in depth, and had a sand bottom interspersed with patches of small gravel. In 1948 the flooded meadows bordered a creek as much as 12 feet wide and averaging a foot deep over a bottom similar to that upstream. There was little silt and such remaining here from past beaver occupancy until the lower reaches of this association, where these deposits were particularly notable on the inward side of bends away from the current. The stream gradually narrowed to eight feet in its final mile or so, where bottom deposits of gravel were most prevalent in the valley between the ridges along the Middle Branch of the Ontonagon River, with a few rocks here and there. Undisturbed holes in this portion of Morrison Creek were a bit more than three feet deep. However, even this area was much altered by the animal engineers during the period of this study.

The headwater beaver ponds in the Morrison system at their various periods of activity were favored by anglers of the vicinity, including some from Wisconsin, who did very well in taking brook trout from a variety of craft with either worms or flies according to the season. The lower fifth of the creek never did rate very high among fishermen, even when some of it was impounded. These reaches were marginal trout water in many respects, with temperature as perhaps the deciding factor, particularly in that so much streamside alder had been killed by flooding. Although the C. C. C. made a rough survey of Morrison Creek for the U. S.

Forest Service in 1939, no improvement work has been done either by them or the Michigan Department of Conservation in the following years.

(2) Beaver Occupancy and Chronology, Lower Reaches

Throughout my work on Morrison Creek, bank beaver were present in the Middle Branch of the Ontonagon River both above and below the mouth of this tributary. It was evidently one of these individuals which built a dam between here and the road bridge in October of 1950. It backed water up to the recording thermograph station eight yards upstream from the highway; the structure was only 30 yards above the creek mouth, and extended back into the brush a short distance each side of the channel. Fashioned mostly of willow and alder, the dam held a foot or so of water, and probably did not survive the severe spring breakup of 1951. The animals had made a start at building a lodge in the east bank, halfway up the pond, which was pretty much confined to the channel; nevertheless this colony, if there was more than one individual, had all the makings of a one-year stand, and no more.

At the start of my research project in June of 1948, the center of beaver activity on Morrison Creek was an active pond a short distance above the road bridge (Figure 13). However, a reoccupancy of the upper dam site in the fall of that year provided most of the information, and

Figure 13. Pond I, Morrison Creek, looking northward from upland to the west.

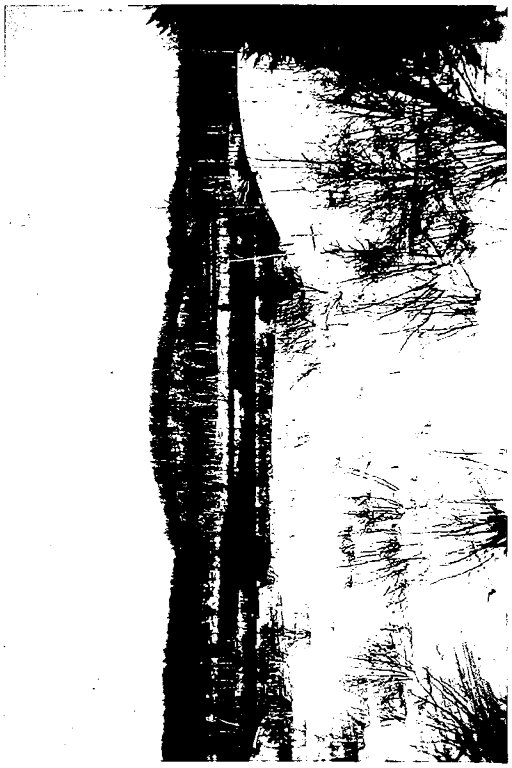
Fall, October 3, 1949

Winter, February 16, 1949



Spring, April 28, 1949

Summer, August 3, 1948



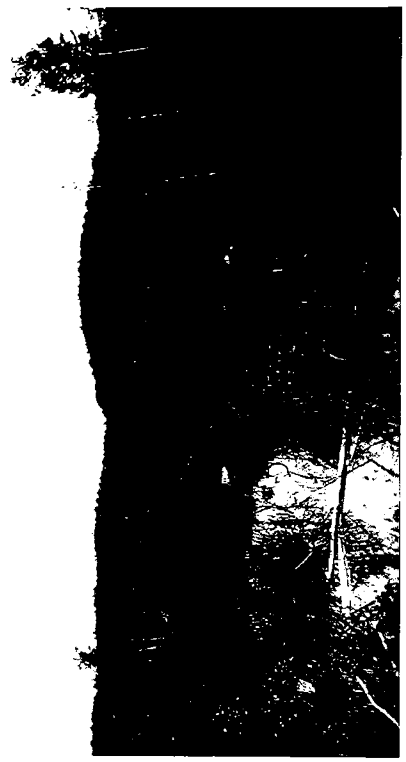


Fig. 13

there were also wintering groups downstream from that locale over both the 1949-50 and 1950-51 seasons. Upstream from Pond I there were more than a dozen decaying beaver dams, which could provide material on the aftermaths of beaver occupancy in contrast to the active colony under study.

The meadow area just above the road had been dammed only slightly by the animals in the summer of 1947, but that fall they moved from Pond II, the flooded area of Figure 12, downstream for the winter. The new construction work was less than 100 feet long, extended from the eastern upland by the original channel across the marsh, but never quite reached the steep western slope. The dam was as much as eight feet wide at the base, and the maximum head of waterwas about 3.5 feet. It was well-built for the most part, except for the western end, which was without any aspen bolts anchored in the marsh to strengthen this extension, through and around which water flowed almost constantly during the summer of 1948. There was a sizable beaver lodge on the east bank at the base of a lone balsam about 40 feet above the dam.

Pond I (Figure 13) was half an acre, with an irregular eastern shoreline and an even one by the western ridge. It narrowed to 40 feet at its head end where Dam II, the home structure in the summer of 1947, had washed through at two former stream channels with an island between them. At the base of this, there was still some sand and gravel bottom, but most of the original substrate was covered with a mixture of silt, detritus, and peat, which in protected areas was more than a foot thick. Back from the creek proper the muck and peat of the original marsh prevailed.

The two ecological units of channel and flooded meadow were not as distinct in the previous Morrison Creek pond as elsewhere. In places the former was as much as six feet deep, and the latter had from two to three feet of water over it at the edge of the original stream. The marginal alder was soon killed, although the willow untouched by the beaver continued to flourish, as did the original lowland vegetation of grasses and reeds, much of which was used by the animals for food or as building material. This particular area had not been subject to frequent beaver occupancy in recent years, and was known to contain several springs. Well-oxygenated but warm water from upstream was affected little in its passage through the pond. As reflected by the outlet temperatures,the surface became heated sufficiently to dominate the sources of cool ground water.

As mentioned above, the lower reaches of Morrison Creek, although accessible to fishing, had never been a strong favorite of the local anglers. Before its flooding, the stream through Pond I had provided some brook trout fishing in the summer of 1947, but a year later it had become dominated by creek chubs. The problem of competition was not studied here the first field season, after which most operations shifted to the upstream beaver colony. Differences in fish food organisms between the channel and the marsh did not prove to be as striking as expected in this pond, and Dam I did not last long enough to be included in any major barrier study related to brook trout spawning movements.

The beaver colony of Pond I included two small and two large individuals as noted during evening observations on July 12, 1948. Ten days later the animals were cutting both upstream on the west slope at the head of this pond and on the east shore just below the dam, which was holding about four feet of water, and had been extended westward. At the end of the month, the western logging operation involved skidding the poplars down an 80°-incline from the extreme crest of the ridge of land to the stream itself.

On August 3rd, a new lodge was under construction at the water's edge 20 yards below Dam II, which then was holding only a few inches of water. The level of the impoundment behind it was two feet or so below what it had been as the home of the colony the previous summer. Additions of fresh mud to Dam I by the former stream channel had strengthened its crest, but the water was still going around the west end, where it was only half a foot deep, to put an inch of overflow on the lowland by the road. By the 13th of the month the backwaters had risen so that the next structure upstream was itself holding only slightly more than an inch.

By the end of August the beaver's logging efforts concentrated on the west slope two-thirds of the way up the pond opposite a clear-cut area on the east side. The animals had commenced mudding their new west shore lodge as early as August 25th; the tempo of operations had increased on the east bank, and included some alder for building purposes obtained from below Dam II. On September 1st the home dam was a bit higher, with surface water running over it in several places as the winterizing efforts increased.

I did not visit Morrison Creek again until winter field trips on February 16 and 21, 1949. About 20 inches of snow lay over the ponds, and the complete ice cover varied from four to six inches in thickness. Although there was no visible chimney effect on either lodge, the beaver had been chewing on a freshly-felled aspen by the newer house. A thaw on the 18th brought on more activity by both these animals and by at least one otter, which had evidently denned in the abandoned lodge of the third pond in this series and may well have put a hole in Dam I before the spring break-up.

In late April, although the beaver had recently been cutting several aspens up the hill to the west of the lodge on that side of Pond I, the water level was down a foot below the high of the previous year, and the creek was flowing through the dam, particularly at the two ends. This drop was reflected at the next structure upstream, which was holding a foot of water 18 inches from its crest. There were fresh beaver cuttings and tracks in the mud below the lodge where the animals had spent the winter, but no work by the home dam was evident on May 2nd.

Heavy rains during the following four days filled the pond to its former level, and the creek was pouring over the east end of Dam I, and also to the west of the old stream channel. The next structure upstream also had its basin filled, and the water was cascading over two beaver crossings. However, on May 9th the impoundments were each again a foot below their respective crests. Scattered signs of the beaver brought hopes that the colony would rebuild the home dam, and plane-table mapping of this study area continued.

With two holes at the east end of Dam I the water level continued to fall: 1.5 feet below the crest on May 20th, down another six inches by the 25th, and 2.5 feet below the peak head on June 14th, when there was still 1.5 feet of water impounded. "Tramp" beaver moved through the area from time to time, but early in June it was apparent that this site had been abandoned. Late in the month the level rose to within six inches of the crest of Dam I following heavy rains, only to have it go down again; and through the summer it remained 2.5 feet below the previous year. However, a backwater of a foot remained in this former impoundment. Sand was exposed at the lower beaver lodge, and various annuals and perennials were fast invading the mud flats on the margin of the stream channel (Figure 14). In mid-September beaver from the Middle Branch of the Ontonagon River were cutting willow on the west shore just above the road bridge and transporting it to their bank dens along the larger stream. Although the water was flowing through the old pond, ice covered its lower quarter on November 22, 1949, in contrast to which a much larger portion of the two active ponds upstream was already frozen over at this early date.

On February 14, 1950 the creek off the lower beaver lodge of Pond I was under 20 inches of snow and three of slush ice, and was just at freezing temperature. The high water of the severe spring break-up came within eight inches of the road bridge, and the entire lowland swamp here was flooded (Figure 14). Dam I remained in place, with but a three-inch head gushing through at the old stream channel on May 6th; bank beaver from the river were cutting aspen on the east slope between the structure and the road. Even Dam II was holding eight inches of water, which was flooding the old pond area behind it.

The high waters of 1950 subsided between May 8th and 20th; they were brown, but not turbid. About a third of Pond I was still flooded on May 24th, and twice as much of the next two areas upstream was still briefly impounded. This gradually went down, and heavy rains in May

Figure 14. Pond I, Morrison Creek, looking northward from upland to the west (compare with Figure 13).

Revegetative stage, September 19, 1949

Spring flood, May 7, 1950

Autumn normal, September 9, 1950

Fig. 14

and June all but washed out the lowermost dam, the sticks of which had been displaced a yard downstream at the channel. The lower half of the pond still had its black bottom, but a portion of the next one above now had scattered patches of light silt, both over and below the former black substrate. The stream's recovery from beaver occupancy of these lower reaches was slow through the remainder of 1950 (Figure 14), and there were no significant changes apparent during brief spot-checks of the creek in late July of the next year.

(3) Beaver Occupancy and Chronology, Middle Reaches

While Pond II was the home of the Morrison colony in 1947, the backwaters overtopped a third dam 30 yards above the main structure. This, which was never active during the present study, was the second of eleven deserted ones in three-quarters of a mile from the stream's mouth to the blown-out dam which in turn was overtopped by the waters of the main upper pond. No one of these works held any head at all during the field season of 1948, but in the course of the project two of the sites were reoccupied by beaver for one-winter stands. Such ponds were not intensively studied, except for the 1950-51 impoundment, which was an integral part of a special barrier-effect investigation. The dams themselves were mostly short structures 20 to 40 yards long extending from one highland to the other; all had been broken through at one point at least, and did not block the passage of fishes in either direction.

The first of the two re-establishments cited above was about three-eights of a mile above the creek mouth. The dam itself was discovered early in the morning of October 5, 1949. This was my first fall field season, and I had been in the habit of visiting both upper and lower study sites regularly and neglecting the stream between them, unaware of the autumn beaver movements, during which dams for the winter grow very rapidly. Such was the case here, where the older Dam VI was used as a foundation for the new 40-yard structure; its base was six feet wide, and it held 2.5 feet of water in addition to the normal one-foot depth of the creek. The impoundment extended upstream three-sixteenths of a mile to Dam IX at the foot of a wide meadow, which had been dynamited by Fish Division personnel in 1935. The pond's lower half was in Section 16, and the upper in Section 21; it was confined between the two ridges, and amounted to slightly more than two acres, with a depth ranging to five feet.

Most of the flooding in the middle reaches of the Morrison was lowland grass, alders long-dead from previous occupancy, and scattered logs. The east slope here was a jack pine plantation with little beaver food at all, but an overstory of aspen above smaller conifers on the other side provided fair forage. The old lodge on the west shore

15 yards above the damsite was rehabilitated, and Dams IV and V were rebuilt as auxiliaries, each to hold about 1.5 feet of water. The latter were of loose construction, and the home dam when first seen had not been mudded for the winter.

Two sections of Morrison Creek were already under study when the preceding new colony was checked during the fall of 1949 for information on the barrier effects to brook trout spawning movements. It remained active during the following winter, but washed out and was abandoned following the 1950 spring break-up. The group at this site included two medium-sized beaver, and at least one yearling, as counted over three October evenings in 1949. Late in this month water was still pouring over both auxiliary dams, and a thin ice border had formed around their edges, extending over half the area of the main impoundment. The home dam was freezing pretty well by November 2nd despite its lack of a solid mud crest. That afternoon, although the air temperature was 23° F. at 2:00 p.m., there was no ice at all; moderate winds may have accounted for its absence.

The heavy rains in mid-November of 1949 did no real damage here, and a few days later the home pond was about half-covered with slush ice, to which an eight-inch snowfall over the night of the 18th had contributed. Three beaver trails between the home dam and the lodge, on which some fresh work had been done, indicated that the animals hadn't yet settled down for the winter. By the 22nd there was a foot of snow on the ground, and all three ponds had an inch of ice over them except for the outlets immediately below the dams; the real freeze-up had come, and there were no longer any fresh beaver tracks in evidence.

The colony appeared to be "holed up" in mid-February, 1950, and there were no signs of recent activity. Almost two feet of snow overlay 15 inches of ice on the home pond, the dam of which seemed to be holding well. Just before the beaver trapping season began, on March 22nd, there was open water at its east end about which the animals had been foraging, and the dam face itself had hardly any ice on it. Otter had been over the structure but there was no sign of any damage; the chimney effect from the lodge indicated that the colony was safe. A week later the beaver had been cutting aspen from the east shore again, and the ice cover remained despite brief, but frequent, thaws.

The home dam was in good shape on May 1st just prior to the 1950 spring break-up and was holding 2.5 feet of water; each auxiliary one had a one-foot head. Numerous fresh sticks were scattered along the west shore all the way from the lodge to the remains of Dam III. On the seventh, when the run-off was at its maximum, these structures appeared to be withstanding the flood despite their weak crests. As the waters subsided the main dam held its 2.5-foot head, but the nearest auxiliary one was a foot below its crest, and there was no fresh sign of any beaver activity here on the 15th. No animals were seen during evening fishing of the largest impoundment here ten days later; however, there were a few newly felled aspens of fair size half-way up the pond on the east shore. Meanwhile the level here was four inches below the crest to provide a head of three feet, while each of the auxiliaries downstream held half this figure.

Into June, there was no beaver activity, and periods of listening for kits within the lodge went unrewarded. The dam still was impounding two feet of water on June 1st, but this was ten inches or so from the top of the structure, in which there was no visible large hole. The basin was again filled to its former level by the heavy rains the night of the eighth only to return to its two-foot status by the thirteenth, when I finally concluded that this had been a one-year stand for the animals.

At mid-June the auxiliary ponds of the colony were each 1.5 feet below their former crest, and the waters behind them covered only a third of their former areas, these being inverted T-shapes to include the portions just behind the structures and up the creek a short distance. At the end of June the home pond was only 18 inches above its outlet, and the secondary dams had heads of about five inches. These conditions continued pretty much unchanged through the remainder of the summer, and revegetation of mud flats was proceeding faster than the natural clearance of silt and detritus from the stream channel of this old pond.

Meanwhile a beaver family, evidently from upstream, had reactivated Dam IX in July only to move a little further downstream to their new auxiliary structure and build it very rapidly during September. This location appeared ideal for a concentrated, all-out barrier study which included erecting a weir just below the newest dam, where there was still four to six inches of water held back by the abandoned 1949 home dam. To lower this and facilitate construction at the trapping site, the one that had failed during the past spring was removed with a 14-stick blast of dynamite on the otherwise quiet Sunday afternoon of September tenth. Most of the water which rushed from the breach was slowed by the dams downstream, and no one of these was significantly affected. The next morning scouting of the exposed mud flats for stranded fish showed only two small mudminnows, a Johnny darter, and several tadpoles. The hole in the dam itself was eight feet wide and about three feet into the original substrate. There were no dead fish either in this vicinity or downstream, whence the water had already been dissipated to the river;

the creek through the abandoned flowages of these lower reaches was back within its banks, although there were successive high water marks down to Dam I. The severe spring break-up of 1951 did not wash away much more of the blasted Dam VI, but the seasonal flood turned out to be too much for the colony which had moved in upstream.

The site of the new colony's first efforts was the mammoth Dam IX, which in the early 1930's had flooded all of the marsh area upstream from its first expansion in the northwest corner of Section 21. The original structure here, judging from the situation during my author's intensive observations, must have held back close to eight feet of water; according to reports, the pond above had provided excellent fishing over a three-year period. However, it was dynamited one evening in the summer of 1935, and the resulting flood of water almost washed out the road grade of the then-highway U.S.-2 just above the mouth of Morrison Creek!

Reoccupancy of the area must have occurred early in July of 1950; the dam itself was discovered and appraised on the tenth. The beaver had utilized considerable material from the old structure as a base for their current operations; alder and grass were the predominant new additions. At first the reconstruction was only 25 feet long in the big gap of the antecedent work, but it finally was extended on both sides of the original stream atop the lines of the former one. The flimsy dam held but two feet of water at this time to flood only a third of the marsh area here; the creek was being impounded in its channel up to the outlet from the main study area to be described later.

This structure too, with only a fair food supply available and considering the lack of binding between the new and the old dams where the two types of material joined, suggested that this was another one-year stand. As late in the study as this, it did not seem practical to conduct any extensive field operations here, but the area was visited from time to time throughout the summer. No lodge was being built or reoccupied by July 24th, when the dam itself was being mudded; however, a month later the animals had been at least investigating the abandoned house at the head end of the pond on the west shore. Meanwhile there had been much crossing of the home dam upstream, which indicated that the new work was being done by the same colony rather than any recent arrivals from elsewhere.

Early in September there was still no sign of any food pile around the old lodge mentioned above, nor anywhere else in this new middle pond. Its level was down half a foot on the sixth and only eight inches of water were trickling through its whole length; meanwhile the outlet had risen a bit more than a foot, thanks to what probably was to have been an auxiliary dam downstream about 40 yards.

This was situated in a 25-yard gap through which the stream passed between two ridges, a site surveyed later in the fall for a possible Pittman-Robertson flooding project, at the head end of the 1949 one-year stand described earlier. Twenty yards above the structure was an old beaver lodge on the west shore, and downstream a somewhat lesser distance were the washed-out remains of Dam VIII, of which little had resisted the passing years. The new work was holding nearly two feet of water, and nearby the animals had been logging building materials of all sorts and sizes. Their efforts were on a good foundation, from which the structure rose rapidly to impound 3.5 feet of water by September 24th.

Following the decision late in August to make an intensive effort to learn more about beaver dams as barriers to brook trout spawning movements, this particular work seemed to be a good choice for a second location on Morrison Creek at which to conduct such a study. The main upper dam did not appear to be a block, whereas this new one had all the makings of such an obstacle, considering its location and height, together with the speed in which it was built.

When the dam was at its maximum crest and fully prepared for the winter, practically four-fifths of the marsh upstream was flooded, which amounted to almost six acres. There was no drowned timber at all in this meadow association, where an additional foot or so of water would have made the area more attractive to migrating waterfowl. The stream channel itself was as much as six feet deep, and its bottom changed little with but a year of occupancy this time. The lower third of the impoundment was still confined between ridges; above this it widened in a big basin, then narrowed to the stream channel below the main upper pond.

In mid-September of 1950 the beaver here shifted their cutting activities to the east shore a third of the way up the impoundment near an old lodge which was rebuilt for the winter and adequately provisioned late in October by a new food pile in the original streambed. Meanwhile the animals' initial attempt in this area, i.e., on the site of Dam IX, had been overtopped by four inches of the backwaters from the newer structure downstream. This continued to have a weak crest with no mud at all to bind the wood and grass, and an outlet channel from its west end entered the creek proper eight yards below. However, at the end of October it was holding fully four feet of water! The lodge and food pile each grew into November, when the pond itself was finally frozen over on the 14th. At this time the dam too was iced in spots where the stream had previously been gushing; the winter cover thus created a true barrier if direct ascent had been the trout's mode of passage.

The colony evidently survived the winter only to have five structural failures at the original stream channel drain the pond following the severe spring break-up of 1951. On July 28th there were still 1.5 feet of water behind the remains, but this was 2.5 feet below the crest, and the area was definitely deserted. The original attempt at blocking the creek upstream atop the old Dam IX was falling to ruin, yet holding eight inches of water in various bays of the old impoundment. The marsh itself had a periodic maximum of three inches underfoot near the old channel due to heavy rains.

(4) Beaver Occupancy and Chronology, Upper Reaches

However, in mid-summer of 1951 the main upper pond still had its usual head of 2.5 feet, which had varied significantly on only a few occasions since its establishment in late August of 1948. This was at least the third flooding of the area in 25 years, and earlier that summer Morrison Creek had been flowing unimpeded through its upper reaches.

This stretch was first cruised extensively on July 27, 1948. The grasses of the beaver meadow were interspersed with long-dead alders at streamside, then dead conifers, live trees of this sort, and finally the hardwood upland. At the head of this vegetative series, there were some young green alders, and numerous springs feeding the creek both in and below the rugged headwater swamp of this brush and varied conifers. Back in 1939 there had been a beaver colony at the Morrison's source in the southwest corner of Section 28, and an old dam in the cedar swamp here was observed from the air on May 10, 1949; however, no family was known to be active in these reaches during my intensive study. In 1948 the upper stream contained two feet of cold water (54°F. at 2:50 p.m.) and was six feet wide, but in the middle stretch by the cabins at the end of the woods road to the west (Figure 12), it was about 12 feet across and only six inches deep over a sand bottom (61°F. at 2:10 p.m., 71°F. at 3:40 p.m.) with no shade at all from the hot sun.

Earlier reconnaissance had included the area above the 1950 middle pond just described. Next upstream from its backwaters were the remains of an aged auxiliary structure in the constriction beyond the first expanse of marsh, and 40 yards above this was a line of tag alders marking the sodded remains of the old Dam XI, which may even have flooded this area before the giant ninth one blasted in 1935. An equal distance upstream was a deep hole in the last dam of the dozen which had been dynamited by a conservation officer in the spring of 1945. This too was at a narrows between the uplands bordering the stream, and was selected as an alternate site for the proposed Pittman-Robertson flooding project on Morrison Creek.

Late in the summer of 1948 the animals again moved into the area, probably in mid-August. The work was discovered September 3rd, when it was holding only 1.5 feet of water. It was only 25 feet across then, but it was both lengthened and raised before winter set in. At the first inspection there was no sign of either a lodge or a food pile, and the beaver were logging aspen scattered among the conifers of the west shore upstream to the blown-out Dam XII.

The following winter (February 16, 1949) the head of water was estimated at two feet below the snow and ice cover, which was a figure equal to that noted the next spring (April 28th). The food supply appeared to be low, but the animals had successfully passed the winter in a new lodge about 20 yards above the dam on the east shore. An auxiliary structure downstream had come to hold 15 inches in its backwaters of only ten yards to the base of the main one. Below this area the creek had been entirely open through the big meadow above Dam IX.

The major impoundment here was just over a mile long, and its average acreage was somewhat greater than a forty. In such a marsh as this, bordered by swamp, the exact delineations of shoreline were difficult to ascertain, even using the Department of Conservation's definition of water as any place that a minnow could swim. The stream channel meandered from one side of the low area to the other in maintaining its northward direction. From this the most important laterad extensions of the pond were two head-water spring holes to the east, the entrance of a tributary from this same direction, and another spring area farther north in Section 21, where there was also a tongue of marsh southwestward from the abandoned cabins. Aside from these the shoreline itself was fairly regular, with gentle undulations for most of its length on either side of the creek.

As mentioned earlier, this stretch before it was impounded had a bottom mostly of sand with a few scattered patches of gravel. The lower half of the pond soon had a coating of silt, detritus, and peat material over the original substrate, and at the end of the second year this extended almost to its head end. Meanwhile the grass areas either side of the old stream bed had been flooded too, and here the lowland peat and muck produced some severe decomposition effects during the hottest part of the summer. Below the dam dynamited in 1945, narrow margins of upland clay were also flooded. The stream channel itself, with the exception of the hole in the old Dam XII and the flooded springs, ranged in depth from three to six feet and had steep original banks. The marsh bordering the creek was flooded with as much as two feet of water off the cabins.

Most of the area had been impounded at least twice before in the preceding 25 years; only in the small, lowermost section between Dams XI and XII were there any trees killed this time. There were alders, for the willows and dogwoods persisted until taken by the beaver for food. The meadow complex seemed to be entirely of species tolerant to flooding, which flourished with their bases covered by the waters of the flowage (Figure 15). Meanwhile great beds of *Ranunculus*, *Potamogeton natans*, *P. foliosus*, and *Polygonum amphibium* developed in the channel at favored locations, and other aquatics such as *Sagittaria spp.* came into the edge between the two major associations. Periodically during the summer months the spring holes and some other areas along the channel proper were the scenes of algal blooms by such genera as *Nostoc* and *Spirogyra*.

The vegetation, however, did not hinder fishing in this water area. Anglers needed a boat or a canoe to reach the upper part of the pond, where the brook trout were favorably concentrated for them around spring flows and/or such good cover as old log jams, fallen trees, and former bridges, particularly in the hottest weather. The beaver-impounded headwaters of this stream were in their third known period of good fishing while I was making my study of the stream, but it was uncertain how long the angling success would last.

Figure 15. Upper pond, Morrison Creek.

Looking upstream from blown-out dam, September 19, 1949

Freezing in autumn above blown-out dam, November 4, 1949

Open in summer at first spring hole, August 24, 1950

Fig. 15

A vital factor in determining how long good trout fishing might be enjoyed here was the physico-chemical conditions which developed. There were extensive zones of both photosynthesis and decomposition to affect the oxygen content particularly, although here again no flooded stand of conifers would alter the pH of the water significantly. Wide unshaded expanses of the pond (Figure 15) raised the temperature appreciably, for some of which rise the spring flow duly compensated. The distinct ecological areas of the impoundment did show different physico-chemical relations, which will be treated in detail in the two sections of experimental material.

The various conditions would be manifested in changes of the fish population itself, which unfortunately was not appraised prior to the beaver's reoccupancy. Brook trout were known to be present before the re-impoundment and also the competitive creek chubs, which might well gain the upper hand in such a situation as evolved here. The fish community could perhaps be split into two or more associations, the channel inhabitants and the marsh dwellers. The original sandy stream bottom had appeared to be relatively unproductive of food organisms, a condition which could get no worse. Both minnow and insect sources of trout forage should increase, and these too might well be grouped into ecological units, reflecting the bottom type and other factors. There were suitable brook trout spawning areas both above and below the impoundment, the dam of which was not known to materialize into the expected barrier to the fall movements of this game fish.

The above anticipations made this a probable study area for the second two field seasons of 1949 and 1950, and this possibility was weighed carefully over the winter following its discovery. The decision to concentrate the work on Morrison Creek in its upper reaches came logically when the lower ponds were abandoned in the spring of 1949.

Around the uppermost area early in May, the beaver were working and cutting only along the lowermost eighth of a mile above the dam itself, which was kept in good repair by the addition of fresh-cut alder already in leaf. Each of the two auxiliary structures downstream was holding a foot of water by the middle of the month, a condition which prevailed to mid-June when the main dam appeared to have been raised another six inches to what was to be its average head of 2.5 feet (Figure 16).

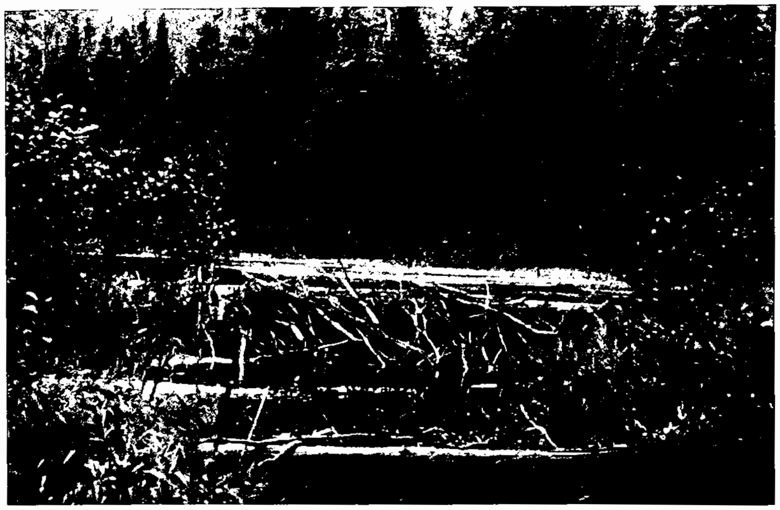
Rains late in June and on July 4th brought much brown water over all three dams for their entire lengths, but did no real damage. Although the two uppermost ones were kept in good repair by the addition of fresh mud and alder, the lowermost was not maintained; the creek flowed through the latter rather than around or over it, and thus its water level was eight inches below the former crest. In mid-July the home structure had become well enough

Figure 16. Upper beaver dam, Morrison Creek.

Early fall, September 19, 1949

Late fall, November 22, 1949

Mid-winter, February 16, 1949



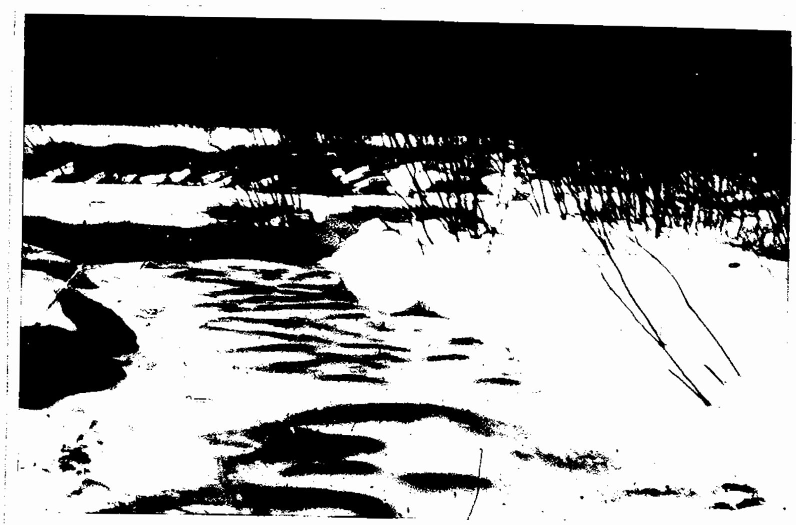


Fig. 16

Figure 16 (continued). Upper beaver dam, Morrison Creek.

Spring thaw, May 1, 1950

High water, May 7, 1950

Summer, July 28, 1951

Fig. 16

established for jewel-weed to gain a foothold atop it. The proximate secondary dam also was neglected by the colony late in the month, a condition which was not rectified during the fall. The levels behind these structures continued to drop, the other one holding but four inches of water early in the autumn.

Two medium-sized beaver had been visiting an abandoned lodge a short distance upstream from blown-out Dam XII intermittently during the summer; they had left food remains there, including fresh-peeled aspen, sticks of alder, and uprooted aquatic vegetation. They had maintained the home dam full to its crest, although there was considerable overflow around its insecure east end late in August.

The lodge in which the animals had spent the previous winter was damaged by what appeared to be a man-made hole 18 inches in diameter at its peak, and in mid-September there was no fresh beaver work evident, either on the dams or ashore. Early the next month the home one was still full to its crest and was holding three feet of water without the addition of fresh material. This condition existed notwithstanding a break two feet wide and four inches deep at the west side of the old stream channel, plus a few smaller ones to the east, and another still larger one on the extension in this direction. However, there were some fresh beaver-peeled sticks in the water off the west shore some distance upstream where the animals had been logging during the summer.

In October of 1949 much wood, mud, and a few aquatic plants were added to the home dam as a part of the winterizing process. Meanwhile the animals were apparently oblivious to a hole in the proximate supporting dam which afforded passage to an otter and/or the numerous muskrats wandering at this time of year. On October 26th water was pouring over the main structure, both at the original stream channel and the overflow one to the eastward. The rate of flow at the Morrison's headwaters continued to keep the sand bottom clear of silt throughout the fall, but off the second spring hole some of this material and fibrous peat had overlaid the original substrate. Here a "tramp" beaver had felled a birch tree during October, stopping to eat only little of the bark. Downstream the members of the regular colony had put some fresh sticks and other re-enforcements on the home dam, and seats behind all the structures suggested that a thorough inspection had been made early in November.

A temporary freeze-up the night of the third provided a cover of three-quarters of an inch of slush ice four-fifths of the way across the stream channel by the deserted cabins, and the lower reaches were similarly icebound by a half-inch thickness. The heavy fall rains in mid-November narrowed this cover to the pond edges. The slush ice increased after the three days of heavy run-off, and the permanent freeze-up came on November 22nd with 12 inches of snow on the ground. At this time the creek was completely ice-covered off the deserted cabins; the only open water in the lower reaches of the pond was at four holes in the channel as large as three feet in diameter where beaver or otter had recently been active. The auxiliary impoundments were clear of ice except 1.5 feet from their margins, and downstream too the creek was still open.

During a moderate snowfall on February 14, 1950, a Game Division snowmobile facilitated a winter visit to this study area through 20 inches of snow. The stream channel itself was now under three inches of slush ice through the main pond, but half the width of the auxiliary impoundments was open. The water level behind the main dam seemed to be down eight inches from the crest of the structure, and there was a sizable flow around the east end of the dam under the snow. Further inspection, despite the insecure ice underfoot, revealed an otter den or temporary shelter at a log in the bank here, and there had been a lot of their activity in the vicinity, judging from scats, tracks, and recently frozen holes in the ice. However, at this time the question of their responsibility for the drop in water level here remained unanswered.

A later inspection on March 22nd before the trapping season opened provided conclusive evidence on this point. The water level by the cabins appeared to be a foot and half below what it had been in the fall, and there were otter tracks extending both upstream and downstream on the opposite shore. The ice here amounted to only an inch, and towards the dam itself, there were two otter holes as it increased in thickness. Ten yards from the east end of the structure and a foot from its top the beaver's rival had pulled and torn away the various materials of which it had been fashioned and thus had lowered the water level ten inches or so (Figure 17). Three distinct layers of ice were apparent: the original one at the crest, a second three inches below this, and an inch at the actual water level. There was no beaver sign at all either around the dam or upstream, and these animals could have been the ones which wintered in the new middle pond a short distance downstream. In this direction the open water below the upper structure was eight feet wide, but the stream was pretty well frozen over through the wide meadow expanse to the north.

Another visit to Morrison Creek a week later during a thaw found the water level still about a foot below its normal height. The stream channel had an inch and a half of ice over it at blown-out Dam XII, and the pond was completely frozen over except for the locales of recent otter activity by the ancient aldered dam, and the

Figure 17. Winter otter activity, Morrison Creek: otter hole in ice (foreground), and that of beaver (right edge), Pond III, February 21, 1949 (upper); and otter hole at main upper dam, March 22, 1950 (lower).

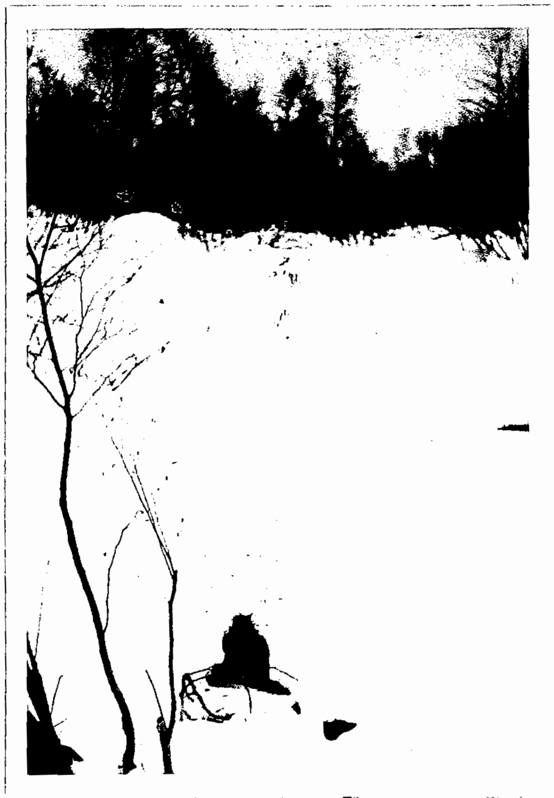


Fig. 17

hole in the main structure. From here the creek was open downstream to the head end of the middle pond 30 yards below blown-out Dam IX. However, the beaver had repaired the damage to the main upper structure by the opening of the trout fishing season, and the pond was full to its crest on May 1st. In spite of this the dam generally did not seem in good shape; notwithstanding the addition of fresh-peeled sticks over the hole made by the otter during the past winter, the water was cascading over the east end and at the former stream channel, and the auxiliaries were each six inches below their crests. There was still about half a foot of snow on the ground, with a thin ice cover over the flooded upper marsh, through which the creek flowed in an open course 15 feet wide.

During the break-up the following week the swollen waters did not prove too severe for this series of dams, although the home one appeared to hold only 1.5 feet of the flood. On the tenth of the month the run-off was subsiding, and the pond was again full to its crest; however, the proximate auxiliary one was a foot below the top of its retainer five days later. Inspection of the lodge of this colony revealed that the overhead hole noted in the fall had been crudely repaired; and the main dam itself was in fair condition with a 2.5-foot head while the two smaller ones below were holding virtually no water at all on May 25th. These were restored by the end of the month when the beaver were also feeding on aspen by their lodge and digging for roots on the opposite shore.

A heavy rain brought the stream proper up six inches the night of June 8th, and when this subsided the main structure had a three-foot head, which was going around each end. The nearer auxiliary suffered somewhat and fell to a foot below its crest; the lower one was all but washed out. On the thirteenth the upper ends of each of these had exposed gravel bottoms, but remained silted in their lower halves. Otter were known to be still around this pond, and one was shot by an angler. Later in the month work by the rodent residents cut down the overflow around the ends of the home dam but the auxiliaries reverted to holding no water at all, and the typical pond bottom type behind them was limited to the off-channel areas, especially just above the structures themselves.

The situation here remained unchanged through the month of July when these same animals were probably the ones hard at work a short distance downstream. Early in August there was sporadic cutting along the west shore between the blown-out Dam XII and the abandoned cabins. Heavy rains at this time weakened the crest of the home dam to lower the water level about four inches, and the beaver had been crossing the structure regularly to the east of the main channel. The ponding effect upstream at the second spring hole was limited to less than half a foot of water over the creek bank proper. However, the head at the dam itself remained fairly stable at 2.5 feet.

The first week of September the animals were felling streamside tag alders between the two auxiliary structures, but the small new one they fashioned held no water at all. The state of the main dam, the level of the impoundment being half a foot below its crest and the creek pouring over a well-worn beaver crossing, did not give it the marks of a barrier to brook trout spawning movements, a hypothesis tested by constructing a weir here and conducting subsequent population studies in the fall season. The trapping device was erected below the proximate auxiliary structure. Meanwhile there were occasional signs of the animals' activity along most of the length of the big flowage.

The beaver made some repairs at their portage over the main dam in mid-September only to have this part of it weakened further by repeated passage of the barge used by the stream improvement crew at work on the weir. In addition to this, there was another overflow 12 yards to the east. The animals continued to visit the area, but laid in no stock-pile of winter food by the lodge; however, they had fashioned a block of the east channel below the main dam. This had a ten-inch head, from which the water escaped by flowing around either side. The home structure on October 9th was holding only two feet, the creek being backed up practically to its base from the new middle impoundment downstream; through the month the three overflows across the former continued, and it seemed to have reverted to the secondary category as far as the colony was concerned.

The winter came on fast in November of 1950. There was hardly any ice around the upper pond on the sixth, but four days later the former stream channel had 2.5 inches of frozen slush, which was thicker and more solid around the margins. The complete, solid ice cover had come as early as the 13th of the month.

A follow-up visit to the area July 28, 1951 found the level in the main upper pond still providing a 2.5-foot head, and there were fresh-peeled sticks by the east shore lodge to indicate that the beaver were still present in this locale. The auxiliary impoundment downstream was holding half a foot of the outlet water, which was a good nine inches below the dam crest. Any damage to the works during the severe spring break-up a few months before had been repaired. However, the animals did abandon the area over the ensuing winter, when the stream was not closed to beaver trapping, for the creek here was back in its original channel when Karl F. Lagler inspected the site for me in June of 1952.

## E. Dynamics of Beaver Ponds

The previous chronologies for three sections of Morrison Creek have indicated that beaver impoundments are very fluid environments rather than ones characterized by slow, regular evolution. During this investigation the animals were active in causing changes on all tributaries of the Middle Branch of the Ontonagon River drainage system. Many beaver ponds functioned over only a single winter, with considerable spring movement following the dramatic high water of the North Country break-ups in both 1950 and 1951. Numerous dams were abandoned because of structural failure rather than because of decrease in available food supplies on the adjacent uplands. The beaver, however, often repaired lesser damage from holes in their structures caused by activities of otter during the winter seasons, or by those of anglers in the open-water periods. There was also considerable movement up and down both large and small streams during the late summer and fall, presumably when the animals were searching for winter homes. Preparations for the cold weather included changes of locations for auxiliary dams and, sometimes, for the actual home pond of a series. In short movements within the colonies, the beaver took advantage of such man-made structures as old logging works, some of which they did not favor for more than one year.

All impoundments studied had fluctuating levels depending on the maintenance activities of the resident beaver. In the fall, preparing for the snow and ice of winter, they seemed to lay in the food supply concurrently with the work on the dams themselves. Thus the smaller branches and tops made up the caches by the lodges, the larger butts provided bark to eat at the time and skinned bolts to place on the dams and houses along with mud to seal the structures. Foraging activities during the winter were infrequent and were limited to occasional mild-weather periods.

When spring floods washed out beaver works and led to their abandonment, pond sites were desolate areas indeed, as they were during any ice-free drawdowns. Although vegetation soon took hold on the drying mud flats of the former flowages, recovery and reappearance of underlying bottom types in the original stream channels themselves appeared to be a much slower process. Unfortunately I was unable to measure such changes effectively in my three-year study period.

For closer examination of the plastic or fluid character of the beaver ponds under investigation, a classification of the changes would distinguish (a) catastrophic happenings--those disasters occurring by chance or accident; (b) long-term evolution--drowning of streamside vegetation in the initial stages and meadow formation following abandonment of the sites; (c) seasonal changes--levels and water-tight integrity, ice cover, and movements of both beaver and trout; and (d) diurnal effects--thermal and chemical features, which constitute the two major sections of this report, and others to be treated subsequently.

### (1) Catastrophic Events

The best example of a disaster on any of the four study areas occurred on the Middle Branch of the Ontonagon River in the spring of 1950 when the ground was still snow-covered as late as May 2nd. Then there were patches of ice and snow along the pond margins, but the channel was open throughout. The beaver had been cutting aspen on the north shore a short distance below their lodge, and to the south of the middle auxiliary dam, each of which work may well have been that of wandering individuals. A 12-foot break in the main dam just south of the old river channel had been caused either by ice action or an angler who had been stalwart enough to fish here over the previous weekend (Figure 18-a). However the water level was only six inches below the crest at this part of the structure, but was down an additional two inches at both ends, which still had half a foot of slush ice. The dam was holding a good 2.5-foot head despite the large break in it, although one of the lodge entrances was now above water. The retaining structure had been in good repair until very recently, judging from the appearance of the lower part of the pond. The damage was finally evaluated as

Figure 18. Failure of main dam, Middle Branch of the Ontonagon River. Compare with Figure 4.

a. Normal, May 3, 1949

b. Weakened, May 2, 1950

c. Broken, May 8, 1950

Fig. 18

Figure 18 (continued). Failure of main dam, Middle Branch of the Ontonagon River.

d. Receded, May 26, 1950

e. Vegetated, July 28, 1951

Fig. 18

due to an ice jam, which had shifted the dam at the south side of the original stream channel.

As the thaw increased, the Middle Branch rose 2.5 feet above normal to reach its highest level in more than a decade! The melting snow from the surrounding upland did not make the water turbid, but the swamp drainage added a distinct brown color. On May 5th some beaver, local or tramps, had been cutting aspen on the north slope between the lodge and the dam, but had made no attempt to strengthen the weakened structure. Patches of ice over about one-sixth of the pond area were now under at least two inches of water. The break was widened and deepened by the flood, and the difference in level above and below the structure was only a foot and a half at the stream channel (Figure 18-b). The water at the south end was eight inches below the crest, and it was four inches over the downstream level as the whole lowland alder swamp was flooded so deep that the depth indicator at the outlet gage station was overtopped by more than half a foot.

The flood had passed by May 8th when the pond water level was way down, with the break in the main dam widened to five yards (Figure 18-c). The river was flowing rapidly through the former pond, its level about 20 inches below the dam crest. A six-inch fall of water dropped from the structure to the flooded swamp below. There was no sign of any rebuilding on the part of the beaver, the presence of fresh-peeled aspen sticks near the outlet gage station notwithstanding.

Two days later the pond water level was down more than a foot below the gage readings of the previous year. The river still had a notable current, but the dam break had less of a fall as the water tumbled to the flooded swamp downstream. There were some fresh beaver tracks around one of the abandoned lodges in the former pond, but any sticks or scats would have been carried away by the high water. The house in which the colony had spent the winter had all of its entrances exposed, and by May 15th the difference in water level above and below the broken dam was only two inches!

Subsequent lack of beaver activity supported the reluctant decision that the animals had left this area. There had been no evidence of any trapping here in late April, but such traces may well have been obscured. The failure of the dam during the severe spring break-up was probably the deciding factor in the abandonment of this Middle Branch pond by the colony. After the waters subsided the crest of the main dam seemed close to four feet above the level of the river, with the uppermost supporting structure still holding eight inches of water. The second one had been washed away completely, and the newest and most downstream effort, although with a four-inch head, was torn out by hand to facilitate evaluating the stream flow data from a U. S. Geological Survey gage station.

Another set of circumstances the same season resulted in repair rather than desertion of a home dam site. Toward the end of March I snowshoed into McGinty Creek on the opening day of the 1950 beaver trappimg season. Ice thickness was not measured, but was estimated as almost ten inches; there had been eight sizable patches of open water in the logging pond, and six in the main flowage which had frozen over again the previous night (air temperature +10°F. at 6:30 a.m., March 25th). The stream was open at the base of each dam, although there were no signs of any recent beaver activity ashore. Otter tracks in the snow were fresh at only one of six spots, being obscured elsewhere by the morning thaw, which reached 44°F. at noon. The lack of beaver sign, combined with the presence of otter, suggested that the latter species might have gotten the better of this colony during the late winter. Subsequent events proved this to be the case.

A thorough examination on May 4th, when the ground was still snow-covered, revealed that the rodents were cutting both aspen and cherry on the north shore downstream from Dam I, and atop the hill near the main structure. However, there was a hole in the old logging dam, probably dug by the otter. This opening had lowered the water level two feet at the channel, and almost three feet at the margins. Meanwhile the rodents had rebuilt the next dam upstream to hold a foot of water despite two sizable overflows (Figure 9).

By the time of the break-up on May 9th the beaver had added fresh material to all three structures from their extensive logging to the north of the ponds. However, the run-off was getting the best of them: the break in the logging dam was three yards wide, and attempts to repair it with grass and fresh-peeled sticks had failed. The head of water was down to about a foot, and the clear, brown McGinty was cascading over to place the pond level two feet from the crest. There were rare patches of ice inshore, and still two inches of it on most of the marsh. Ice was absent from the main pond, at the head of which the water was about 1.5 feet above normal, and the grass was just starting to green. The lodge and home dam appeared to be in good shape, the latter still holding 2.5 feet of water. The stream was pouring over the rebuilt auxiliary dam, which now had less than a foot as its head.

This secondary structure did not change in two days, following which the flow through the logging dam was only six inches above the level of the outlet downstream, and that still 1.5 feet above normal. The most critical circumstance was at the home structure, where a regular tunnel appeared (Figure 19). This had evidently

Figure 19. Otter damage to main dam, McGinty Creek study area. Lower photo of frontispiece shows results of repair of this break.

Normal spring condition, May 12, 1949

Looking upstream early in spring, March 25, 1950 (left); and looking downstream later in spring, May 11, 1950 (right).

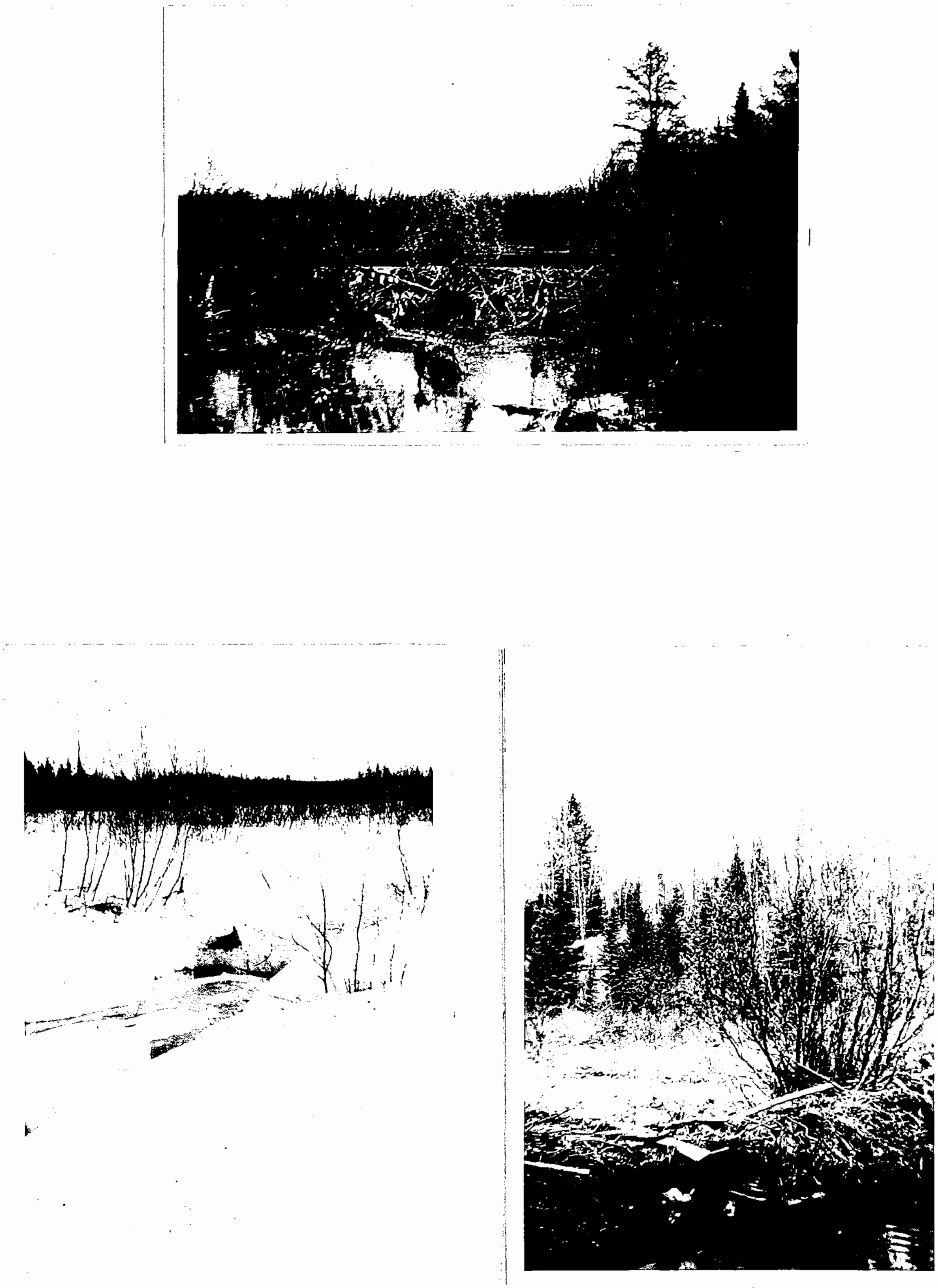


Fig. 19

been excavated by the otter during the winter, then given makeshift repairs by the colony, which did not stand the strain of the heavy run-off. As a result the water level was down 2.5 feet from the crest and was only half a foot above that of Pond I. However, there were fresh beaver tracks in the mud at two places along this impoundment's margins.

The animals had begun to rebuild the logging dam by May 23rd, when fresh mud, sticks, and grass gave it a head of 15 inches. The auxiliary one above it was in poor condition with only half a foot of water impounded; a short-term lodge on the south shore was falling to pieces, and a system of tunnels had undermined the whole side of the bank here to a distance of six feet from the house proper. There was a large gravel bar in the channel just downstream from the break in Dam II, which had been exposed by high water. Only an eighth of the main pond below the blown-out dam was still flooded; the peat and silt bottom, with its numerous logs, was slowly drying (Frontispiece). The lodge itself had three entrances exposed, and the stream bottom nearby was cleared to sand and gravel, on which there were numerous sticks from old food piles (Figure 10).

It wasn't until June 13th that the beaver made a start at repairing the main dam, and on that date it was holding only half a foot of water. They had built a U-shaped cofferdam around the break in the logging one downstream, to which fresh sticks and grass were added from time to time. Willow incorporated in this structure the preceding year had sprouted and was flourishing in six clumps. Within three days the head of Dam II had been raised to a foot by a fair amount of fresh alder, and the beaver had been foraging as far as the extreme head end of the main pond for these trees.

By June 19th the pond level here on the McGinty was even with the top of the old stream bank (Figure 11), and that at the dam itself was half its height a year ago, with a foot and a half of the structure yet exposed. In four more days the repair efforts were almost complete, although no mud or grass had been used to bring the water within six or eight inches of the former crest. This was going over only at the old stream channel and two beaver crossings, and very little seemed to be percolating through the interstices. Meanwhile there had been no work on the logging dam. The animals had added some fresh grass and mud to Dam II at the end of the month, and the main structure at last was again at its original crest on July 1st, with water going over it at very few places. The beaver had also shown interest in their former lodge in this pond, where they had fed on aspen cut up the slope to the north.

A scouting trip to the East Branch of Bluff Creek July 29, 1951, found the situation much changed from the previous fall, and some of the dams meanwhile had failed in an apparently catastrophic manner. The second one of the series, in good condition with a two-foot head, was sodding in rapidly without any fresh beaver work; the third, with half again as much water behind it, was full to its crest. The severe break-up, however, had torn a five-yard hole at the southwest end of Dam IV to leave this pond level 1.5 feet below normal. Yet, the scene of real desolation was the next one above, which had a similar-sized rip in its mid-section (Figure 20). This left many watered bays and channels, rather than a flow confined to the original stream course of the Bluff, which the beaver had made almost five feet deep. Although neglected by the animals, Dam VI was but half a foot below its crest and in fair condition with a 2.5-foot head of water.

(2) Long-Term Changes

An opportunity to study some effects of this sort came on the Middle Branch of the Ontonagon River in 1950. Rather than selecting another stream on which to follow beaver-trout relations for only one season, my superiors and I elected to continue observations here to note the recovery of this area from the damage done by the animal's occupancy (Figure 21). In mid-May of 1950, sporadic signs of "tramp" beaver along the stream were noted, but

Figure 20. Pond V, upper series, East Branch of Bluff Creek.

Lodge when active, October 4, 1950

Lodge when abandoned, July 29, 1951

Break in dam, July 29, 1951

Fig. 20

Figure 21. Main beaver pond, Middle Branch of the Ontonagon River.

Full, August 20, 1948

Drying, May 26, 1950

Dried, October 13, 1950

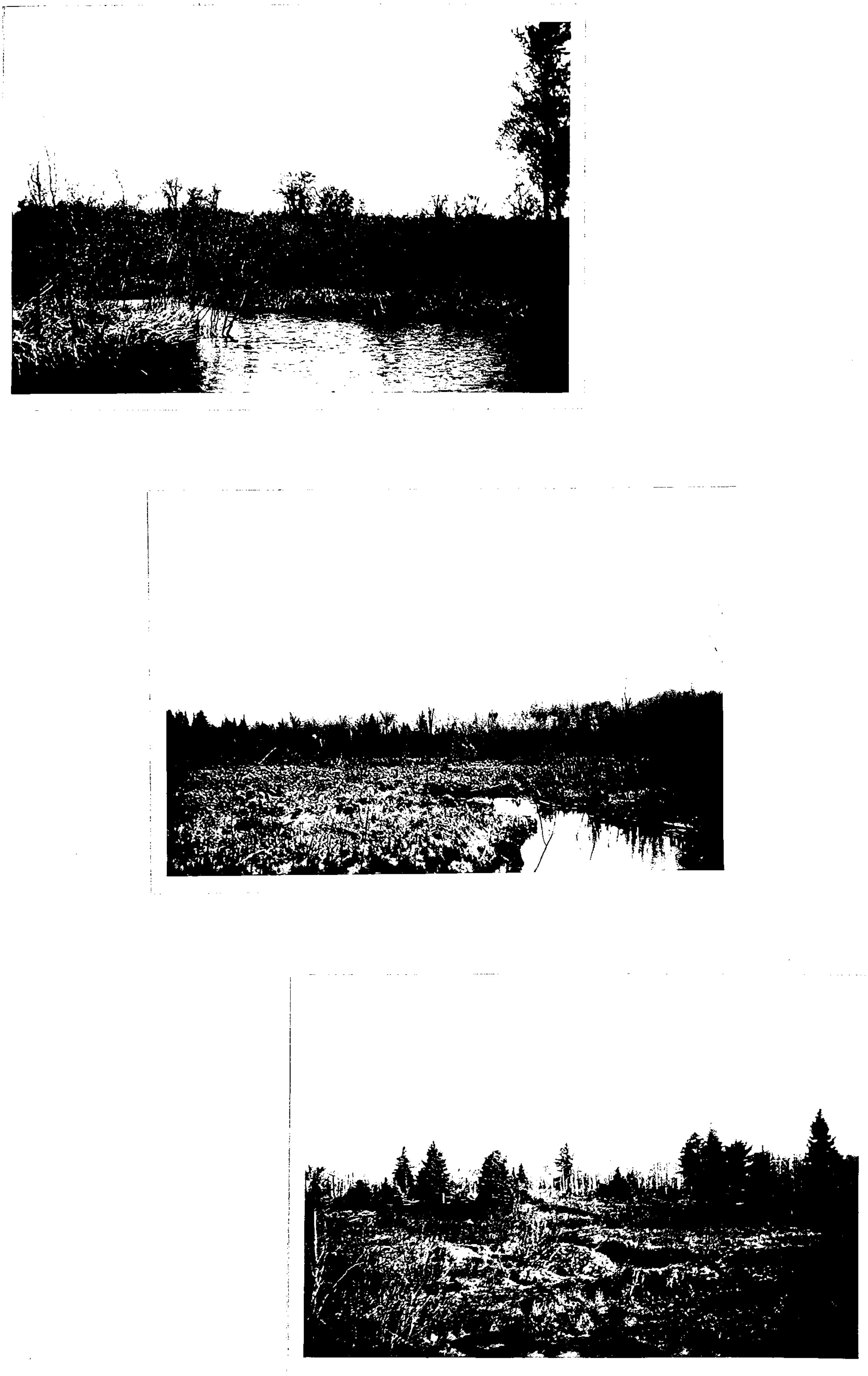


Fig. 21

construction activity was confined to the upper end of the meadow far from the original dam site and did not occur until late in the summer. Towards the end of the month the stream channel above the washed-out dam had only a few silt bars, a thin layer of this sort over the sand bottom, and no visible gravel at all. The sand substrate definitely predominated in this area, much silt having been carried downstream by the flood waters. Meanwhile the two auxiliary ponds were eight and three inches respectively above the level of their outlets.

On June 12th the Middle Branch was flowing through the break at least three feet below the former main dam crest. Sand and silt from the home pond had covered most of the bottom in the small supporting one immediately downstream. Although the typical beaver area material had mostly been removed from the lower part of their home pond, no gravel was exposed by this date. The sand of an extensive bar below the dam may well have come from the structure itself rather than the firm pond bottom; the beaver had used much of this material in their building activities. Some gravel was exposed at the bends of the upstream river channel, but the gradient here was much lower than that of the rocky portion above these reaches.

By the twenty-third a lot of very small gravel had been bared in the former auxiliary ponds; yet the bottom here was sand and silt for the most part. Into the summer the slow change in type of substrate type continued, and on July 19th the auxiliary pond was appraised as 20 percent small gravel, five percent large gravel, five percent peat, and the remainder a combination of sand and silt. By this time the main pond was about ten percent small gravel, with much more sand than silt elsewhere in the formerly impounded area.

In this stretch of the river more gravel was being exposed all the time, but silt and debris, plus the original sand, made up most of the bottom. By early September there were still no real holes except for those dug by the beaver, and these were inshore. Trout cover along the channel edge was fair, consisting of alder roots, old snags, flood debris, and undercut banks. The auxiliary dam just below the main structure still had an eight-to ten-inch head of water despite the channel cut through it at the south end, and silt extended to within a foot of its crest; then upstream from a stretch of shallow gravel were some rocks just below the wash-out.

(3) Seasonal Variations

The beaver colonies under intensive observation all showed generally similar seasonal patterns. The animals remained in the same home areas for at least two winters, although their auxiliary activities often changed among the waters both up- and downstream from the main impoundments. Cutting of food increased sharply in the late summer and fall seasons to stockpile supplies for the coming winters; meanwhile both the dams and lodges were repaired for the cold weather.

The group on McGinty Creek remained over four winters in the same home pond, but their secondary efforts shifted in locale. In early July of 1949 the animals turned to the site of the logging dam downstream from their base of operations and used the structure as a foundation for a new auxiliary of their own system. It rose to hold 2.5 feet of water by July 11th, was of loose construction initially, but became more solid with time. The head increased to four feet during August and the backwaters came to cover the crest of Dam I. During the late summer the home area was neglected until mid-September, but in the next month preparations for winter were well underway: cutting food, strengthening the two retaining structures, and mudding both of the foregoing and the lodge. The home dam held only two feet of water when the ice cover started to form as early as November 8th.

Seasonal events during the late summer and fall of the next year followed those of 1949 in general, but there were some significant changes in beaver activities. The most notable of these was the virtual abandonment of the former logging dam until early in October. Meanwhile Dam I, the original auxiliary of this colony, was not well maintained, although it still had a head of 15 inches in September. The main structure held 3.5 feet of water at this time and rose another six inches by November to reach its highest crest, as shown in the frontispiece. The old logging impoundment had almost reverted to mud flats when the beaver rebuilt the retaining structure. Their work provided a 15-inch head by the freeze-up November 16th when the auxiliary dam upstream had been reenforced to hold three inches less.

Whereas the McGinty Creek Colony had included only three dams, the beaver of the Bluff Creek group shifted their activities back and forth between the six upper ponds. In August and early September of 1949 extensive work on Dam VI indicated that the animals intended to use that uppermost pond as their home for another winter, but on October 4th the retaining structure had a minor break 20 yards from the south shore, which lowered the water a foot. Late the previous month a lodge rose rapidly in Pond V, and the fifth dam itself had a good 2.5-foot head on October 13th. Foraging and logging efforts were concentrated on the south slope and produce an extensive food pile for the winter; ice formation commenced November 3rd.

The structures of the previous colony survived the severe spring break-up of 1950 with no noticeable damage; both the dams and their pond levels were stable by the end of May. Through the summer Dam V was the best maintained of the six in the series as the animals were concentrating their efforts on the structures which were necessary for their current activities. Apparently the others were being allowed to deteriorate until needed again by the animals. The lodge in Pond V was greatly enlarged and heightened in September (Figure 20-a), and the sixth dam had been restored through extensive repairs. The home structure was holding more than four feet of water by the freeze-up of mid-November, and the impoundment covered most of the two sizable food piles on each side of the old stream channel near the big lodge. Cutting operations had included work in a stand of aspen at the head of Pond VI where a small auxiliary dam aided in transport.

The happenings on the Middle Branch of the Ontonagon parallelled several of those on the two streams described above. Here, as on the McGinty, the beaver maintained one home dam while the colony was active, and their auxiliary operations changed from one site to another. The shifting nature of activity was particularly evident in the late summer of 1949 when the animals rebuilt one secondary structure, then erected a new one downstream only to abandon it in mid-October and return to the first locale. However, the auxiliaries seemed to have been left in poor condition for the approaching winter. Maintainance efforts were concentrated on the home structure concurrently with work on the lodge itself. Both of these were in good shape for the complete freeze-up on November 22nd despite the highest water of the fall season a week earlier.

III

## TEMPERATURE EFFECTS

Two constant characters of the beaver ponds which I studied in Michigan are that in summer they warmed the affluents and similarly influenced varying lengths of the streams below their dams. The magnitude of these effects differed from one creek to another, depending upon such factors as the ground-water supply, the amount and distribution of shade both in the impoundment and downstream, the extent of flooding, and the volumes of inflow and outfall. At other seasons the thermal characteristics of the beaver ponds under intensive observation did not differ significantly from those of the natural, flowing portions of the streams. This investigation failed to locate an instance of autumnal super-cooling, which Salyer (1935-a) regarded as a cause of failure of fall brook trout spawning in impoundments of this sort. During the severe cold periods of winter, open water and that under the ice were generally in a narrow range of 32-34°F.

Temperature readings through most of this project were taken at regular intervals and at established stations on the primary study areas. During the summer of 1948 all records were taken with Taylor etched stem, 5-1/2-inch pocket thermometers which had a range of -40° to +120°F. in two-degree divisions. For the following two seasons maximum-minimum instruments supplemented the pocket type and provided records for temperature range over a period of time in addition to spot readings. These thermometers were Taylor, 10-inch, so-called six's pattern, and also had a range of -40° to +120°F. in two-degree divisions. A recording thermograph was used in a special test on Morrison Creek.

Fishery biologists have recognized for some time that high water temperatures in summer are frequently the limiting factor of trout productivity in marginal streams, a concept that will be examined thoroughly later. In this regard the extremes over periods of 24 hours or a week are more significant than mean or median values, which would not indicate either the highest temperature (bringing on possible distress during the heat of the day) nor the lowest figure (usual recovery over the cooling night). Actual mortality of brook trout comes at some point above 80°F., and the fish are probably uncomfortable at 75°F., depending on acclimatization rates as well as thermal extremes. The latter figure is designated as critical in the tabular records from study streams in accordance with Embody (1922).

Interpretation of the various readings over three field seasons, 1948-1950, is complicated by the differences in climate during these years (Table 2). The weather station operated by the U. S. Forest Service at Watersmeet was established in 1939 and provided the "normal" figures for the total period of the record, and meteorological data during my study.

Table 2. Evaluations of certain meteorological conditions, Watersmeet Area, 1948-1950 seasons.*

*Figures from Climatological Data, U.S. Weather Bureau

| Year | Month | Average air temperatures(°F.) Maximum | Minimum | Mean | Departure from normal | Total precipitation (inches) | Departure from normal |
|---|---|---|---|---|---|---|---|
| 1948 | May | (90)68.6 | (22)32.8 | 50.7 | -0.9° | 0.37 | -4.23" |
| 1948 | June | (90)74.1 | (25)44.0 | 59.0 | -2.2° | 2.45 | -3.54" |
| 1948 | July | (92)81.1 | (29)50.6 | 65.9 | +0.7° | 2.42 | -0.73" |
| 1948 | Aug. | (96)79.8 | (32)48.2 | 64.0 | +0.8° | 3.02 | -1.05" |
| 1948 | Sept. | (89)75.9 | (21)39.9 | 57.9 | +3.0° | 0.72 | -3.16" |
| 1948 | Oct. | (75)57.1 | (15)31.3 | 44.2 | +0.2° | 1.07 | -1.04" |
| 1948 | Nov. | (68)39.3 | (10)26.0 | 32.6 | +2.9° | 3.61 | +1.35" |
| 1949 | May | (88)69.4 | (20)37.8 | 53.6 | +2.0° | 4.71 | +0.11" |
| 1949 | June | (91)79.7 | (21)50.9 | 65.3 | +4.1° | 5.90 | -0.09" |
| 1949 | July | (91)80.6 | (35)54.6 | 67.6 | +2.4° | 5.17 | +2.02" |
| 1949 | Aug. | (90)78.0 | (28)49.1 | 63.6 | -0.2° | 2.82 | -0.72" |
| 1949 | Sept. | (76)65.6 | (18)40.7 | 53.2 | -2.2° | 2.38 | -1.04" |
| 1949 | Oct. | (74)62.4 | (21)34.6 | 48.5 | +3.0° | 2.99 | +0.95" |
| 1949 | Nov. | (64)38.0 | ( 7)20.4 | 29.2 | -0.5° | 2.88 | +.55" |
| 1950 | May | (85)63.2 | (21)35.4 | 49.3 | -1.5° | 2.44 | -1.44" |
| 1950 | June | (87)75.7 | (27)46.3 | 61.0 | +0.5° | 4.73 | -1.11" |
| 1950 | July | (84)74.1 | (35)47.1 | 60.6 | -4.7° | 3.58 | +0.71" |
| 1950 | Aug. | (85)72.3 | (28)42.2 | 57.2 | -6.2° | 3.91 | +0.37" |
| 1950 | Sept. | (80)66.8 | (19)40.8 | 53.8 | -1.6° | 0.81 | -2.61" |
| 1950 | Oct. | (80)59.4 | (21)35.3 | 47.4 | +1.9° | 1.86 | -0.18" |
| 1950 | Nov. | (79)33.2 | (-15)15.3 | 24.2 | -5.4° | 3.82 | +1.44" |

NOTE: Figures in parentheses indicate extreme readings each month.

For the most part the summers of 1948 and 1949 were warmer and drier than the overall record, whereas that of 1950 was cooler and wetter. These differences tended to obscure any evolution of increased warming as the ponds got older and more stream-side shade trees and brush were killed by flooding, but the weather complication was more serious in relation to chemical phenomena affecting fishes, particularly the oxygen content of the water, than on the temperature per se.

## (A) Summary of Thermal Characteristics of Study Streams

### (1) Middle Branch of Ontonagon River

For comparison with water temperatures taken above, in, and below the beaver pond west of Watersmeet, I had reference to thermal data taken at the Ontonagon Trout Rearing Station about six miles downstream from my study area. Here the caretaker took readings three times daily from a semi-permanent installation at 8 a.m., noon, and 5 p.m.

Three maximum-minimum stations were established June 13, 1949, around the beaver pond toward the headwaters of the Middle Branch of the Ontonagon River. The most upstream of these, the so-called inlet station, was in a well-shaded stretch just east of the Wolf Lake road bridge, whence the water flowed half a mile through equal distances of timbered fast water and the head of the beaver pond under observation. The thermometer in the impoundment was mounted on a stump at the edge of the old stream channel 20 yards above the dam itself to record from a depth of two feet, and thus to escape surface effect and to provide readings perhaps typical of the major part of the pond's volume. About 60 yards downstream from the primary retaining structure, and below all of the auxiliary ones, an outlet thermometer was secured to a log which extended across the stream channel; this registered the temperature of the water flowing from the area of beaver occupancy. The pond station was not maintained in 1950 following the washout of the main dam, but the others were read two or three times a week as they had been over the previous season.

Pocket thermometer readings during the summer of 1948 were taken unsystematically at three stations: (1) about one-third up the pond, (2) by the dam crest, and (3) at the foot of the dam. These did not show any significant overall change in temperature around the lower end of the impoundment, and indicated that the stream was cooled slightly during its passage through this short stretch, particularly towards the dam, where cool water from the depths could circulate with the warmer strata near the surface. In ten instances during both morning and afternoon the differences ran as follows in degrees F. (frequency in parentheses), pond surface <u>vs</u>. stream below dam: +2(1), 0(5), -1(1), -2(1), and -3(2). However, few of the readings were taken late in the afternoon after the full effect of radiation; thus they were more nearly average values rather than those of excess warming, which was rare here too in the following years.

During 14 weeks in the summer of 1949, temperatures of more than 75°F. occurred only three times, with a maximum of 77°F. for these reaches of the Middle Branch (Table 3). When the main dam was no longer functioning the next year, the highest reading was 74°F. Thus in no instance was the trout population severely jeopardized by undue warming or by overly rapid temperature change.

For 1949 maximum temperatures show an average overall rise through the study area of slightly less than one degree. This elevation occurred between the inlet and the pond stations (Table 3). During the much cooler summer that followed, the effect was the same even though the dam was no longer an obstruction. In half the weekly readings of 1949 there is evidence of favorable temperature recovery downstream in the half-dozen miles to the Ontonagon Trout Rearing Station. The number increased to nearly three-quarters in the next year (Figure 22). Either this difference progressing downstream was an artifact which stemmed from the timing of readings at the latter location, or the action of tributaries and springs, plus evaporation, in actually cooling the water made it more favorable for trout production.

A combination of several factors probably explains the absence of any severe warming effect from the large beaver pond on the Middle Branch of the Ontonagon River. The half-mile between the inlet and pond thermometer stations included two distinct ecological units which had opposite effects on

Table 3. Weekly Water Temperature Ranges and Changes between Stations on the Middle Branch of the Ontonagon River, 1949 and 1950.

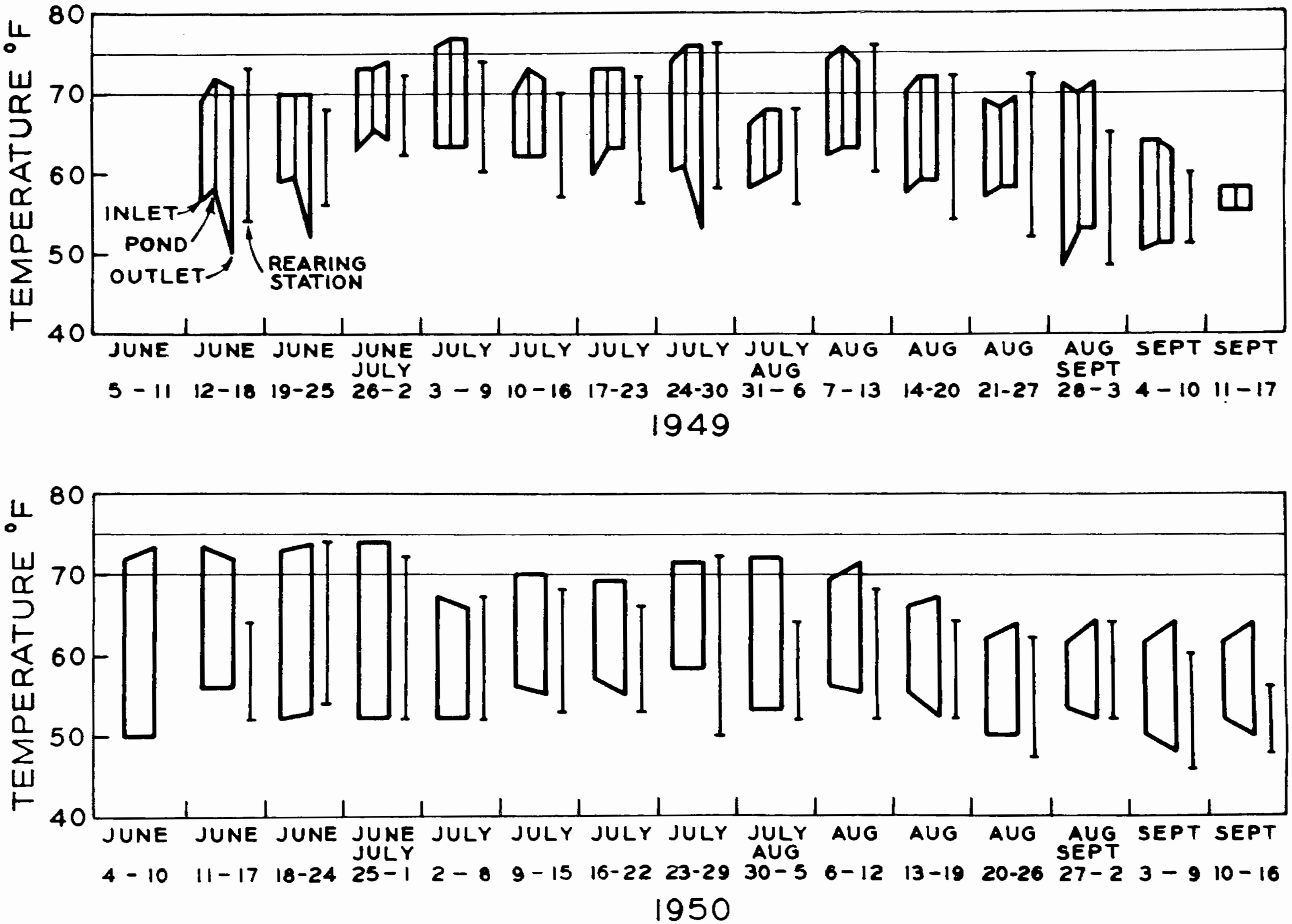
LOCATION AND TEMPERATURE (°F.)

| 1949, Week beginning | Inlet station | Change in maxima | Pond station | Change in maxima | Outlet station | Overall change | 1950, Week beginning | Inlet station | Change in maxima | Outlet station |
|---|---|---|---|---|---|---|---|---|---|---|
| June 12 | 69 - 57 | +3* | 72 - 58 | -1 | 71 - 50 | +2* | June 11 | 73 - 56 | -1 | 72 - 56 |
| June 19 | 70 - 59 | 0 | 70 - 60 | 0 | 70 - 52 | 0 | June 18 | 73 - 52 | +1 | 74 - 53 |
| June 26 | 73 - 63 | 0 | 73 - 65 | +1* | 74 - 64 | +1 | June 25 | 74*- 52 | 0 | 74*- 52 |
| July 3 | 76*† - 63 | +1 | 77*- 63 | 0 | 77*- 63 | +1 | July 2 | 67 - 52 | -1 | 66 - 52 |
| July 10 | 70 - 62 | +3* | 73 - 62 | -1 | 72 - 62 | +2* | July 9 | 70 - 56 | 0 | 70 - 55 |
| July 17 | 73 - 60 | 0 | 73 - 63 | 0 | 73 - 63 | 0 | July 16 | 69 - 57 | 0 | 69 - 55 |
| July 24 | 74 - 60 | +2 | 76 - 61 | 0* | 76 - 63 | +2* | July 23 | 71 - 58 | 0 | 71 - 58 |
| July 31 | 66 - 58 | +2 | 68 - 59 | 0 | 68 - 60 | +2* | July 30 | 72 - 53 | 0 | 72 - 53 |
| Aug. 7 | 74 - 62 | +2 | 76 - 63 | -2 | 74 - 63 | 0 | Aug. 6 | 69 - 56 | +2 | 71 - 55 |
| Aug. 14 | 70 - 57 | +2 | 72 - 59 | 0 | 72 - 59 | +2* | Aug. 13 | 66 - 55 | +1 | 67 - 52 |
| Aug. 21 | 69 - 57 | -1 | 68 - 58 | +1* | 69 - 58 | 0 | Aug. 20 | 62 - 50 | +2 | 64 - 50 |
| Aug. 28 | 71 - 48 | -1 | 70 - 53 | +1* | 71 - 53 | 0 | Aug. 27 | 61 - 53 | +3* | 64 - 52 |
| Sept. 4 | 64 - 50 | 0 | 64 - 51 | -1 | 63 - 51 | -1 | Sept. 3 | 61 - 50 | +3* | 64 - 48 |
| Sept. 11 | 58 - 55 | 0 | 58 - 55 | 0 | 58 - 55 | 0 | Sept. 10 | 61 - 52 | +3* | 64 - 50 |
| Mean change, 14 weeks | | +0.9 | | -0.1 | | +0.8 | | | +0.9 | |
| Number critical weeks | 1 | | 2 | | 2 | | | 0 | | 0 |

* Maximum weekly figure.

† Critical temperatures (>75°F.) underlined.

Figure 22. Weekly water temperature ranges, 1949 and 1950, Middle Branch Ontonagon River, inlet, pond and outlet (left to right vertically in each polygon), compared with rearing stations.



TEMPERATURE °F
80
70
60
50
40
INLET
POND
OUTLET
REARING STATION
JUNE 5 - 11
JUNE 12-18
JUNE 19-25
JUNE JULY 26-2
JULY 3 - 9
JULY 10-16
JULY 17-23
JULY 24-30
JULY AUG 31-6
AUG 7-13
AUG 14-20
AUG 21-27
AUG SEPT 28-3
SEPT 4-10
SEPT 11-17
1949
TEMPERATURE °F
80
70
60
50
40
JUNE 4 - 10
JUNE 11-17
JUNE 18-24
JUNE JULY 25-1
JULY 2 - 8
JULY 9-15
JULY 16-22
JULY 23-29
JULY AUG 30-5
AUG 6-12
AUG 13-19
AUG 20-26
AUG SEPT 27-2
SEPT 3 - 9
SEPT 10-16
1950


Fig. 22

the water temperature: a well-shaded piece which probably included various cooling factors, and then the open headwaters of the impoundment proper, in which it was warmed. As we have seen, the latter effects prevailed by a narrow margin. The readings reflect the difference between these two influences, but not their actual magnitudes.

The lack of additional heating between the pond station and the outlet might signify that the volume of surface water was low, as the spot readings of 1948 led me to believe. The temperature differences between the surface and the thermometer above the dam,which may not have been suitably located, amounted to as much as four degrees, but this stratification may not have been pronounced at other times. The supporting ponds in their various stages of activity and decay in 1949 could have contained a cooling influence themselves from the dam to the outlet thermometer. Yet the fact stands out that the mean difference in maximum readings from the first to the third station was the same each year, with and without the impoundment. The volume of cool water flowing through it was probably much greater than that stored in the exposed marginal backwaters, and thus the warming was not significant either year on such a large stream. Some spring seepages did enter the pond; however, no effort was made to locate them or to measure their contributions. The channel through the flowage was not shaded either summer, and the overall temperature effect was the same each year; what warming there was seems to be inherent in this part of the stream rather than being caused by the lateral spreading here in 1949. Hence this particular beaver dam did not, and perhaps could not, warm the waters of the Middle Branch of the Ontonagon River significantly, and at no time during three summers of observation did temperature conditions here constitute a serious hazard for the resident brook trout population.

(2) East Branch of Bluff Creek

In the evaluation of temperature data from this stream, the several distinct ecological units of the 2.5-mile study area must be borne in mind. Progressing downstream, these included (a) the cool headwaters, (b) the upper beaver ponds, (c) a stretch of long-abandoned beaver work, which had a varying amount of shade, (d) the ponds which were active only in the first year of this study, and (e) the well-sheltered reaches down to the U.S.-45 culvert.

During 1948 the Bluff was not intensively studied, but the following year it became a primary area of investigation which was visited weekly. Four maximum-minimum thermometers provided temperature readings in 1949, and three in 1950. Their locations, five in number, were as follows: (1) the headwater spring run entering Pond VI of the upper series (Station A, 1949 and 1950); (2) an outlet station below this beaver colony (Station B, 1949 and 1950); (3) the trail midway between the upper and lower ponds half a mile below the former (Station C, 1949, but spot readings only in 1950); (4) the outlet from the work of the downstream colony (Station D, 1949); and (5) the U.S.-45 culvert (Station E, 1950). Water temperatures taken by the district fisheries biologist in the last area from July 7 to August 24, 1948, ranged between 53° and 62°F., while the air varied from 60° to 78°F. on these occasions (Anderson, 1949). These values are closer to those from the headwaters than to thermometer readings taken August 20th of the same year by me around the most downstream pond of the upper series and by the lower impoundments in the first of ten temperature series of various portions of this creek which were taken during the three-year study (Table 4). Five of these which included figures for both Dam I and Dam VI of the upper series show a rise of from 5° to 9°F. in the passage of five ponds, and additional warming took place in the sixth one.

On several occasions readings were taken at the surface, at depths of two feet, and at the outlet of the six dams using a pocket thermometer. From three significant series (Figure 23), other manifestations besides the rise in temperature *per se* are evident. The close agreement of surface and outlet readings on August 8, 1950, indicated that the downstream flow came mostly from the upper strata of the various impoundments, the dams of which were old and rugged enough to permit little

Table 4. Temperature Series, East Branch of Bluff Creek.
(At each station, the values are given in order from left to right: surface, submerged two feet, and outlet, in degrees Fahrenheit)

| Date and time | Range of air | Dam VI | Dam V | Dam IV | Dam III | Dam II | Dam I | Lower II |
|---|---|---|---|---|---|---|---|---|
| <u>1948</u> | | | | | | | | |
| Aug. 20, 2:00-5:00 p.m. | 69-73 | 63 .. 60 | 63 .. 61 | 66 .. 65 | 70 .. .. | 70 .. .. | 68 .. .. | 69 .. .. |
| <u>1949</u> | | | | | | | | |
| June 3, 11:20-12:35 p.m. | 75-77 | 59 .. .. | 58-55 .. | 64-61-63 | 65-63 .. | 68-65 .. | 68 .. .. | 68 .. .. |
| June 9, 10:00-11:40 a.m. | 54-54 | 49-47 .. | 50-49 .. | 54-53 .. | 59-57 .. | 59-57 .. | 57 .. 58 | 55 .. .. |
| <u>1950</u> | | | | | | | | |
| June 15, 10:00 a.m.-Noon | 70-74 | 63-56-60 | 63-59-63 | .. 61-64 | .. .. 68 | .. .. 67 | .. .. 67 | 63 .. .. |
| June 20, 1:45-3:15 p.m. | 58-60 | | | 60-60 .. | 61 .. .. | | .. .. 62 | 59 .. .. |
| June 27, 9:40-11:20 a.m. | 65-66 | | | 58 .. .. | 59 .. .. | | .. .. 59 | 56 .. .. |
| July 11, 1:40-4:00 p.m. | 80-83 | | | 75-68-74 | 76-70-76 | | .. .. 75 | 71 .. .. |
| Aug. 8, 10:00 a.m.-Noon<br>1:00-5:00 p.m. | 71-76 | 70-59-69 | 70-62-70 | 71-66-71 | 79-69-76 | 78-73-77 | 76-76-77 | 71 .. .. |
| Aug. 14, 2:30-3:50 p.m. | 63-65 | 55-54 .. | | 61-60 .. | 65-65 .. | 66 .. .. | .. .. 64 | 60 .. .. |
| Sept. 6, 2:45-4:45 p.m. | 66-72 | | 62-56 .. | 64-60 .. | 67-60 .. | | .. .. 66 | 61 .. .. |
| <u>1951</u> | | | | | | | | |
| July 29, 12:30-3:00 p.m. | 79-82 | 81-63-70 | .. .. 70 (broken) | 80-68 .. (broken) | 78-69-75 | 75-69-72 | 73-73-73 | 70 .. .. |

Figure 23. Water Temperature Series, East Branch of Bluff Creek

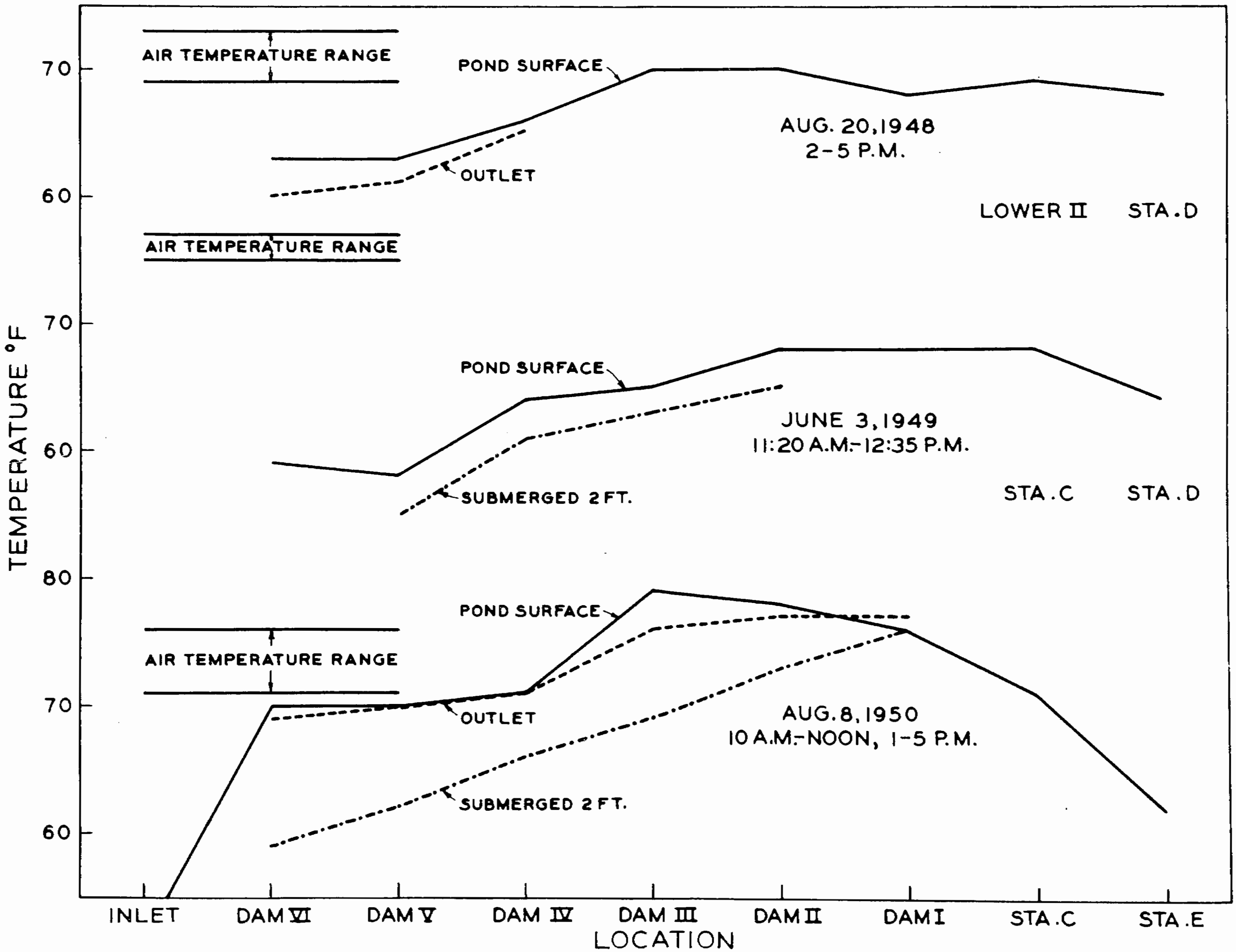

AIR TEMPERATURE RANGE
POND SURFACE
AUG. 20,1948
2-5 P.M.
OUTLET
LOWER II
STA. D
AIR TEMPERATURE RANGE
POND SURFACE
JUNE 3,1949
11:20 A.M.-12:35 P.M.
SUBMERGED 2 FT.
STA. C
STA. D
POND SURFACE
AIR TEMPERATURE RANGE
OUTLET
AUG. 8, 1950
10 A.M.-NOON, 1-5 P.M.
SUBMERGED 2 FT.
70
60
70
60
80
70
60
TEMPERATURE °F
INLET
DAM VI
DAM V
DAM IV
DAM III
DAM II
DAM I
STA. C
STA. E
LOCATION

Fig. 23

seepage of the cooler bottom waters. Stratification at Dam VI amounted to as much as 11°F. that year, an effect which was less pronounced progressing downstream along this series, and was not evident at all by Dam I. This phenomenon was less pronounced on August 20, 1948, and June 3, 1949, than on August 8, 1950.

The warmest the headwaters ever became during two summer seasons, each 13 weeks long, was 62°F., based on figures from maximum-minimum thermometers. The coolest readings were always in the 40's (Tables 5 and 6). Coursing downstream through the half-dozen small beaver ponds, the maximum water temperature rose as much as 23°F. (August 14, 1950). The mean rise in this stretch was 15.8°F. the first year, and 18.2°F. over the second. The former figure is doubtless somewhat low, considering that the outlet instrument at Station B was broken in August of 1949; following this mishap, only spot readings were used for comparison the remainder of that year. The greater warming the second summer may indicate that the increase in this effect reflected aging of the ponds over just a year's time, or the cooler weather overall in 1950 may have accentuated the hot spells of the second summer. The water at the inlet (Station A) was cooler throughout that season.

At least half the upper ponds on the Bluff were themselves spring-fed, but the rise in temperature through them

Table 5. Water Temperature Ranges and Changes between Stations on the East Branch of Bluff Creek, 1949.

| Date | Station A (upper inlet) | Change in maxima | Station B (upper outlet) | Change in maxima | Station C (half-mile downstr.) | Change in maxima | Station D (lower outlet) | Overall change (maxima) |
|---|---|---|---|---|---|---|---|---|
| | LOCATION AND TEMPERATURE (°F.) | | | | | | | |
| June 15 | (54)* | +14 | (68) | -2 | (66) | 0 | (66) | +12 |
| June 22 | 58 - 46 | +17 | 75† - 60 | -3 | 72 - 58 | +6‡ | 78 - 54 | +20 |
| June 30 | .. .. | ... | 76 - 58 | -2 | 74 - 60 | +2 | 76 - 64 | ... |
| July 7 | 62‡ - 48 | +16 | 78 - 60 | -2 | 76‡ - 60 | +2 | 78 - 60 | +16 |
| July 14 | 60 - 47 | +11 | 71 - 60 | -1 | 70 - 58 | +2 | 72 - 57 | +12 |
| July 22 | 56 - 46 | +20 | 76 - 60 | -3 | 73 - 57 | +3 | 76 - 54 | +20 |
| July 29 | 58 - 46 | +22‡ | 80‡ - 60 | -4‡ | 76‡ - 56 | +3 | 79 - 56 | +21‡ |
| Aug. 5 | 56 - 46 | +14 | 70 - 58 | -2 | 68 - 56 | +2 | 70 - 54 | +14 |
| Aug. 11 | 59 - 49 | +20 | 79 - 64 | -3 | 76‡ - 60 | +4 | 80‡ - 58 | +21‡ |
| Aug. 18 | 58 (54) 48 | +18 | (72) | -4‡ | 71 (68) 58 | +4 | 75 - 58 | +17 |
| Aug. 26 | 56 (56) 43 | +18 | (74) | -4‡ | 70 (70) 54 | +3 | 73 - 50 | +17 |
| Sept. 1 | 56 (48) 42 | +10 | (58) | -2 | 71 (56) 49 | +4 | 75 - 46 | +19 |
| Sept. 15 | 54 (44) 42 | + 9 | (53) | -1 | 62 (52) 49 | 0 | (52) | + 8 |
| Mean change, 13 weeks | | +15.8 | | -2.5 | | +2.6 | | +16.4 |
| Number critical weeks | 0 | | 6(+?) | | 3 | | 7 | |

* Spot reading with pocket thermometer.
† Critical temperatures (> 75°F.) underlined.
‡ Maximum weekly figure.

Table 6. Water Temperature Ranges and Changes between Stations on the East Branch of Bluff Creek, 1950.

| Date | LOCATION AND TEMPERATURE (°F.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Station A (upper inlet) | Change in maxima | Station B (upper outlet) | Change at times of rdg. | Station C (half-mile downstr.) | Change at times of rdg. | Station E (Highway U.S.-45) | Overall change (maxima) |
| June 15 | (53)* | +14 | (67) | -4 | (63) | -1 | (62) | +9 |
| June 20 | 58†- 43 | +18 | 76‡(62) 54 | -3 | (59) | -3 | 66 (56) 49 | +8 |
| June 27 | 58†- 44 | +20 | 78 (59) 55 | -3 | (56) | 0 | 67†(56) 49 | +9 |
| July 5 | 54 - 46 | +13 | 67 (63) 54 | -2 | (61) | -5 | 60 (56) 51 | +6 |
| July 11 | 56 - 46 | +19 | 75 (75) 58 | -4 | (71)† | -8† | 63 (63) 51 | +7 |
| July 19 | 57 - 44 | +19 | 76 (63) 57 | -4 | (59) | -1 | 61 (58) 52 | +5 |
| July 25 | 56 - 44 | +15 | 71 (62) 57 | -3 | (59) | -1 | 61 (58) 52 | +5 |
| Aug. 1 | 57 - 48 | +21 | 78†(69) 60 | -4 | (65) | -5 | 64 (60) 56 | +7 |
| Aug. 8 | 54 - 44 | +21 | 75 (70) 55 | -3 | (67) | -5 | 64 (62) 52 | +10† |
| Aug. 14 | 55 - 43 | +23† | 78†(64) 57 | -4 | (60) | -5 | 65 (55) 50 | +10† |
| Aug. 29 | 54 - 42 | +21 | 75 (60) 50 | -4 | (56) | -3 | 62 (53) 47 | +8 |
| Sept. 6 | 52 - 41 | +16 | 68 (66) 52 | -5† | (61) | -7 | 57 (54) 46 | +5 |
| Sept. 12 | 53 - 44 | +17 | 70 (56) 50 | -3 | (53) | -2 | 56 (51) 49 | +3 |
| Mean change, 13 weeks | | +18.2 | | -3.5 | | -3.5 | | +7.1 |
| Number critical weeks | 0 | | 8 | | ? | | 0 | |

* Spot reading with pocket thermometer.
‡ Critical temperatures (> 75°F.) underlined.
† Maximum weekly figure.

indicates that the surface warming predominated (Figure 24). The outlet from these beaver impoundments was not favorable to trout for parts of at least six intervals in 1949, and the corresponding number of instances in 1950 totalled eight of the 13 weeks for the season. Considering the breakage mishap mentioned above, water temperatures warmer than 75°F. probably occurred an equal number of times in the first year when maximum readings for the last fortnight of August, which is often a hot period, were unavailable.

The temperature of Bluff Creek immediately downstream from the upper series of beaver ponds was critical for brook trout at least once in more than half of 26 weekly intervals of the two summer seasons. From such severe conditions the run coursed northward through moderate shade and gained a generous supply of spring seepage to Station C. This combination cooled the water as much as 5°F. in 1950, and three times in 1949 the reduction amounted to 4°F., means for these two years were 3.5 and 2.5°F. respectively. Over the earlier season these readings were from maximum-minimum thermometers, but spot temperatures only were available for comparison during the latter one. However, the 1949 summer conditions here were not favorable over portions of only three periods, a figure which was half that established for the temperatures at the next station upstream during 1949. The cooling in this piece of Bluff Creek was thus decidedly beneficial to the resident brook trout population.

Figure 24. Water temperature readings, East Branch of Bluff Creek, 1949 and 1950, from maximum-minimum (vertical lines in polygons) and pocket thermometers (x). (1949, left to right: Station A - upper inlet, Station B - upper outlet, Station C - half-mile downstream, and Station D - lower outlet; 1950, left to right: Stations A -C as in 1949, and Station E - U.S. highway 45.)

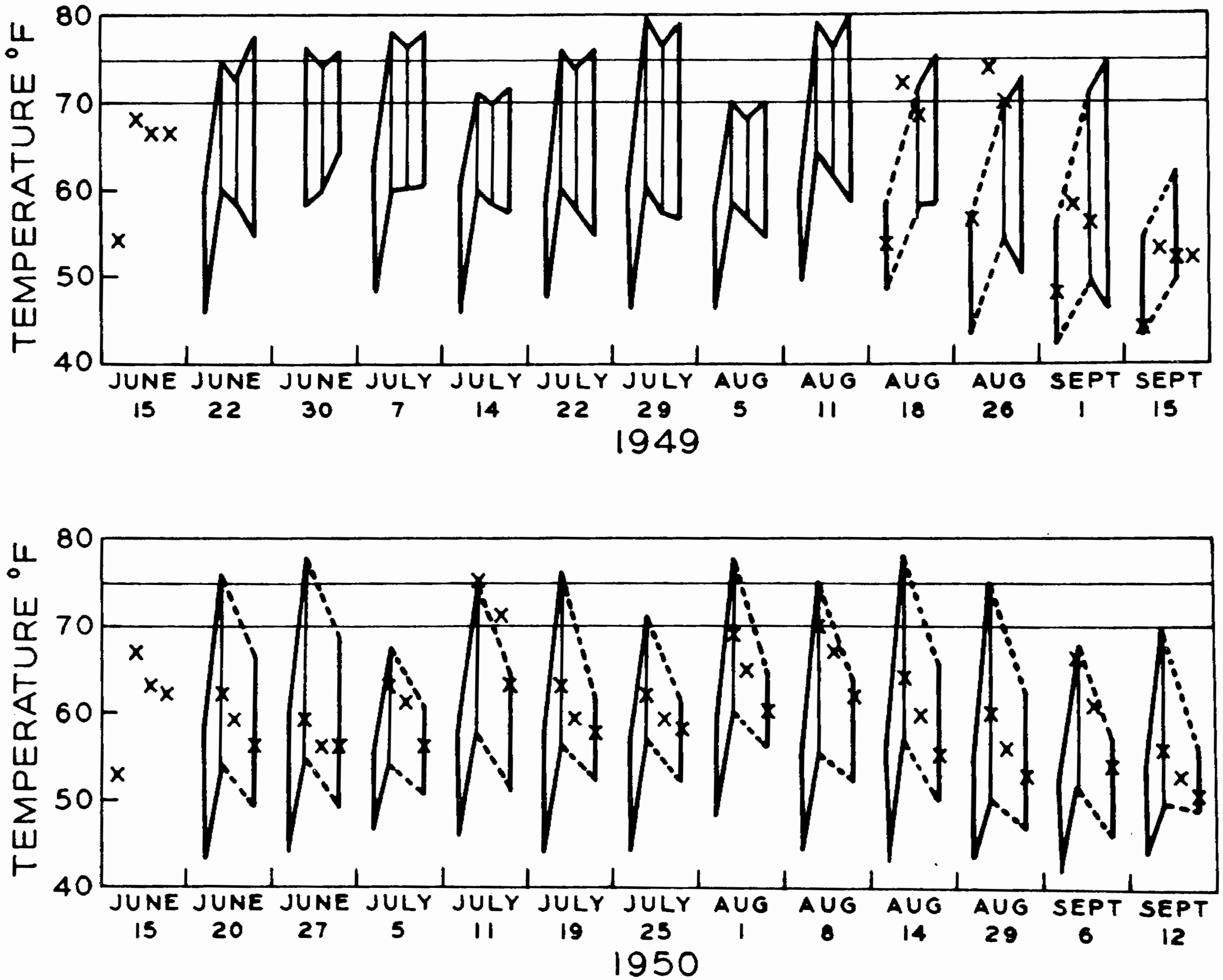

TEMPERATURE °F
80
70
60
50
40
JUNE 15
JUNE 22
JUNE 30
JULY 7
JULY 14
JULY 22
JULY 29
AUG 5
AUG 11
AUG 18
AUG 26
SEPT 1
SEPT 15
1949
TEMPERATURE °F
80
70
60
50
40
JUNE 15
JUNE 20
JUNE 27
JULY 5
JULY 11
JULY 19
JULY 25
AUG 1
AUG 8
AUG 14
AUG 29
SEPT 6
SEPT 12
1950

Fig. 24

The effect in the foregoing reach of stream was counteracted in an equal length of water below Station C; this stretch included some long-abandoned beaver ponds and two more impoundments which had been deserted as recently as the spring of 1949. In neither of these old flowages was there streamside shade or much ground-water addition. Over the summer of 1949 the temperature in this zone rose as much as 6°F. in some weeks, and the mean increase of the 13 maximum readings was 2.6°F. This is one-tenth more than the corresponding figure for the recovery in the next upstream portion of this creek. Here again the highest reading was 80°F., as it had been at the outlet of the upper ponds, although these figures were not registered on the same day. Critical warming occurred here over seven intervals of record in the one-year period, once more than the known instances of such at the upper outlet.

The overall rise in maximum temperature from the headwater spring to the fourth station downstream was as much as 21°F. twice during the season of 1949, and the mean net change, based solely on the highest readings for each interval, was 16.4°F. (Table 5). The next year an instrument was not in position at the outlet of these lower ponds, but instead the station was shifted downstream to the U.S.-45 crossing where low spot readings had been recorded in 1948. This relocation presented a different picture of the temperature effect in the lower reaches of the study area (Table 6).

Instead of the water being warmed, as it had been in 1949 through the lower abandoned beaver ponds below Station C., the rise in this stretch was more than balanced by the cooling process further downstream. The overall difference in spot readings from the culvert to the next station above was as much as 8°F., with a mean decline of 3.5°F. in these figures during the summer, due to the generous shade and good supply of additional cold ground water.

At the U.S.-45 station, the highest temperature of 1950 was recorded as 67°F., and at no time was the water thermally critical for brook trout in this portion of Bluff Creek. Over the whole two miles from Station A to the highway (Station E) the maximum rise in temperature was 10°F., a value just less than half the increase to the next upstream station the previous year, which amounted to as much as 21°F. over two intervals. The average difference declined a similar magnitude, from a warming of 16.4°F. in 1949 in the shorter length of creek under observation to only 7.1°F. in 1950 through a longer study area.

The harmful temperature effects of the water flowing from the upper beaver ponds were thus corrected upstream from the crossing of highway U.S.-45. The lower third of this unimpeded reach had the most significant cooling, a process which occurred to a lesser intensity in the upstream third; however, between these two there was an area of abandoned ponds in which the creek was warmed considerably. The headwater beaver ponds were well provided with cold water for the resident trout population there, although the heating of the surface layers was the factor which dominated their outlet temperatures.

(3) McGinty Creek

Temperatures were critical to this stream's trout productivity as based on pocket thermometer readings at various locations around the two ponds of the beaver colony in 1948. The overall rise through the two impoundments in this year had a mean value of only 1.2°F. at stations halfway up the main pond and at its dam, stratification in the top two feet of water during August amounted to as much as 9° and 10°F. respectively, differences that reflected the numerous springs which entered the impoundment over its whole length. Proceeding from the upper meadow to the more protected lower part of this flowage, the surface temperature declined as much as 6°F., but on another occasion it rose 5°F. Over a dozen comparative sets of readings, there was virtually no mean gain at all (0.1°F.); but eight differences in submerged records were always on the positive side to average an increase of 3.6°F., the maximum being 7°F. Thus the cooler spring water supply gradually lost its effect through this pond, while the corresponding surface temperature differences depended on various factors that may have prevailed.

In proceeding over and through the dam, the two sorts of water were mixed, and it seems that the underlying layer was warmed rather than the top flow being cooled to any great extent. For nine occasions the temperature decline from the latter to the outlet averaged 0.4°F., whereas the rise above the former, which was checked only three instances, had a mean of 2.0°F.; this evaluation means that the surface water prevailed in the outlet flow. Temperature changes through the auxiliary pond appeared to be negligible, and below this the creek in turn was warmed in its passage through the old logging pond, and then cooled flowing between aldered stream banks to the bridge.

In 1949 and 1950, temperatures critical for trout survival were encountered on several occasions. Records came from the following locations: Station A at the head of the home impoundment, Station B in Pond II eight yards above the main dam, and Station C below the auxiliary structures.

During seven fortnights of the 1949 summer, the maximum temperatures of the water entering the pond on the McGinty were critical for trout at least four times, and the highest reading here was 80°F. (Table 7). Unfavorable conditions of the affluent proper occurred during only one week the next year when the mercury reached 76°F. late in June. In 1949 the mean difference through the impoundment over 14 weeks was a reduction of 1.1°F., but the next season the change averaged

Table 7. Weekly Water Temperature Ranges and Changes between Stations on McGinty Creek, 1949 and 1950.

LOCATION AND TEMPERATURE (°F.)

| 1949, Week beginning | Sta. A (inlet) | Change in max. | Sta. B (Pond II) | Change in max. | Sta. C (outlet) | 1950, Week beginning | Sta. A (inlet) | Change in max. | Sta. B (Pond II) | Change in max. | Sta. C (outlet) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| June 12 | 80*† - 46 | -10* | 70 - 54 | +4 | 74 - 56 | June 11 | 72 - 53 | .. | (70)‡ | .. | 75 - 54 |
| June 19 | 72 - 52 | 0 | 72 - 55 | 0 | 72 - 57 | June 18 | 73 - 47 | .. | (72) | .. | 78* - 50 |
| June 26 | 72 - 52 | +2 | 74 - 58 | -2 | 72 - 59 | June 25 | 76* - 48 | .. | .... | .. | 78* - 53 |
| July 3 | 76 - 57 | -3 | 73 - 59 | -5 | 68 - 60 | July 2 | 65 - 50 | .. | .... | .. | 69 - 53 |
| July 10 | 73 - 53 | 0 | 73 - 56 | -3 | 70 - 59§ | July 9 | 71 - 53 | .. | (64) | .. | 76 - 59 |
| July 17 | 74 - 46 | -2 | 72 - 56 | +4 | 76 - 61 | July 16 | 70 - 50 | +8* | 78* - 54 | -5 | 73 - 55 |
| July 24 | 78 - 54 | -5 | 73 - 62 | +5 | 78 - 65 | July 23 | 68 - 51 | +3 | 71 - 55 | +3 | 74 - 56 |
| July 31 | 72 - 48 | 0 | 72 - 56 | -2 | 70 - 60 | July 30 | 68 - 50 | +5 | 73 - 54 | +2 | 75 - 54 |
| Aug. 7 | 77 - 48 | +1 | 78* - 57 | +2 | 80* - 60 | Aug. 6 | 70 - 49 | +2 | 72 - 55 | +6 | 78* - 55 |
| Aug. 14 | 72 - 48 | -2 | 70 - 59 | +6* | 76 - 62 | Aug. 13 | 67 - 46 | +1 | 68 - 50 | +6 | 74 - 48 |
| Aug. 21 | 68 - 46 | -1 | 67 - 54 | +5 | 72 - 57 | Aug. 20 | 64 - 44 | -1 | 63 - 49 | +7 | 70 - 50 |
| Aug. 28 | 72 - 42 | +1 | 73 - 52 | +2 | 75 - 62 | Aug. 27 | 64 - 46 | 0 | 64 - 53 | +5 | 69 - 52 |
| Sept. 4 | 62 - 42 | +3 | 65 - 51 | +2 | 67 - 54 | Sept. 3 | 64 - 43 | -4 | 60 - 52 | +9* | 69 - 50 |
| Sept. 11 | 62 - 42 | 0 | 62 - 50 | +1 | 63 - 52 | Sept. 10 | 64 - 47 | 0 | 64 - 52 | +6 | 70 - 53 |
| Mean change, 14 weeks | | -1.1 | | +2.2 | | Mean change, 9 weeks | | +1.6 | | +4.3 | |
| Number critical Weeks | 4 | | 1 | | 5 | | 1 | | 1 | | 6 |

* Maximum weekly figure.
† Critical temperatures (>75°F.) underlined.
‡ Spot readings in parentheses.
§ Thermometer moved.

1.6°F. warmer. The larger figure reflected extreme surface warming in one instance during July, 1950; however, all the rest of the pond readings were dominated by the cooler spring water. This particular maximum was the only critical one of the second year, and another 78°F. had been recorded the previous summer.

Proceeding downstream from Station B, the rise in temperature was fairly consistent, except for a month prior to the reoccupancy of the logging dam, when the outlet maximum over four weeks averaged 0.8°F. less than the corresponding figures in the main beaver pond. During the remainder of 1949 the increase through the newly occupied area as well was limited to 6°F., and the next season the highest figure was half again as large. The mean rises of the maximum temperatures each year from Stations B to C were 2.2 and 4.3°F. respectively.

In the summer of 1949, the creek below the three beaver ponds was as hot as 80°F., and nearly this warm on four other dates. The highest reading the following summer was 78°F., which was reached during three weeks; in addition, values of 75 and 76°F. were registered. Four of the half-dozen total of critical periods came early in the season when the main dam was still washed out; the other two occurred with it in a good state of repair.

The overall warming in 1950, expressed as the mean of the differences between the maximum readings at inlet and outlet stations, was 5.9°F. when the main pond was functioning, and only 3.8°F. without it. The year before, with the logging structure rebuilt, the rise was 1.7°F., and without it a decline of 3.5°F. was evident as an average for the earliest month of record. The flow of spring water within the main pond may have been sufficient in this interval to prevail over the warming of the surface both here and in the auxiliary pond, a situation which was reversed when the animals shifted their activities some distance downstream to flood a wide and long unshaded impoundment. In 1949 the greatest increase was 5°F. and in 1950 8°F.

Further examination of the temperature phenomena from McGinty Creek helps define the causes of their fluctuations (Figure 25). With the logging pond again flooded by a dam, an overall rise in temperature through the beaver-occupied area occurred every week of record in both years except for two in July of the earlier summer. The major warming effect was in this rebuilt pond rather than in the main one, which was adequately supplied with spring water. Temperatures thus provided were generally favorable for trout survival through hot weather in the latter area. However, 1948 spot observations and others in later years showed that the outlet temperatures from this flowage reflected high surface readings and

Figure 25. Weekly Water Temperature Ranges, McGinty Creek, 1949 and 1950. (Left to right; Station A - inlet, Station B - Pond II above main dam, and Station C - old and new outlets.)

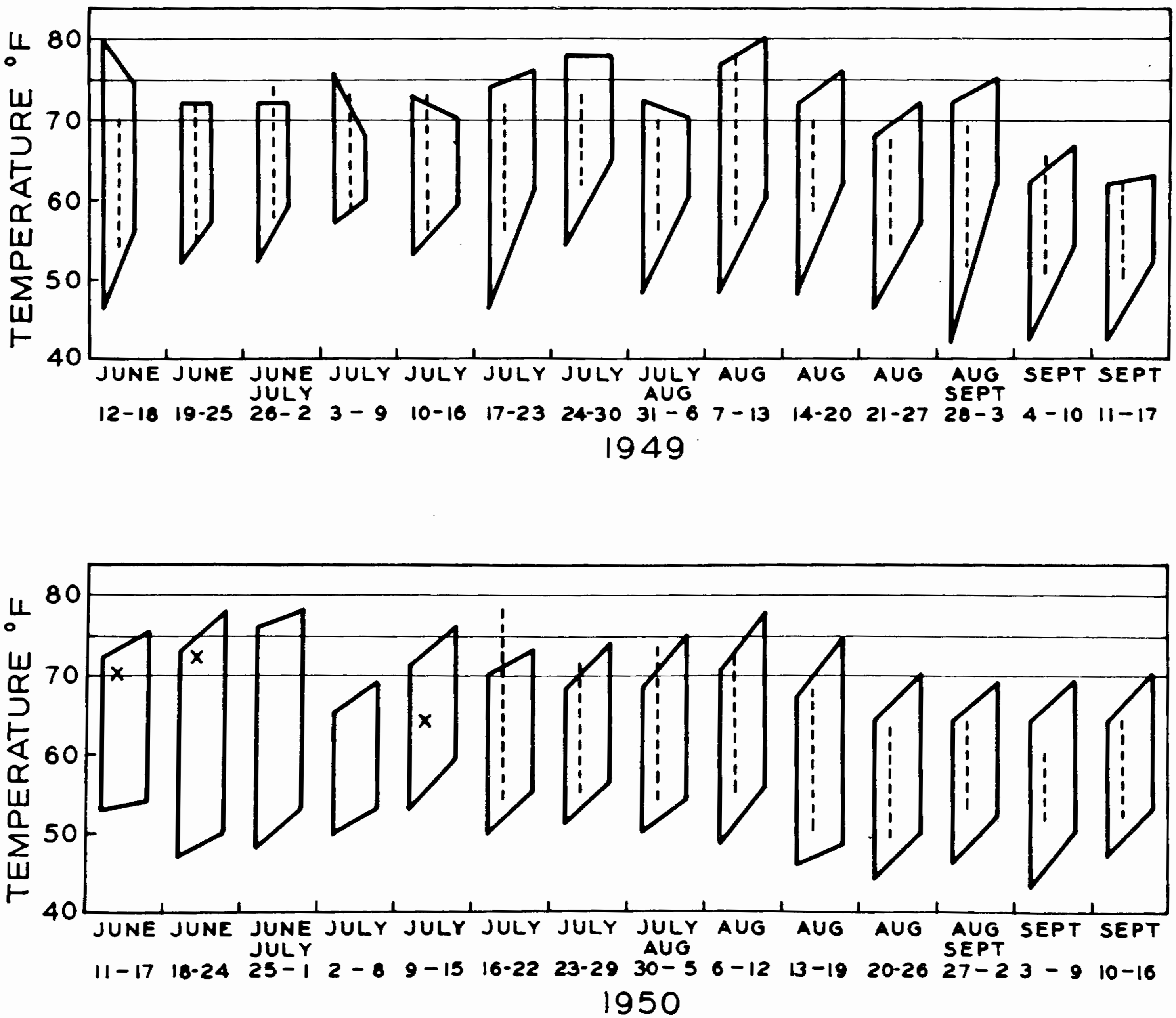

TEMPERATURE °F
80
70
60
50
40
JUNE 12-18
JUNE 19-25
JUNE JULY 26-2
JULY 3-9
JULY 10-16
JULY 17-23
JULY 24-30
JULY AUG 31-6
AUG 7-13
AUG 14-20
AUG 21-27
AUG SEPT 28-3
SEPT 4-10
SEPT 11-17
1949
TEMPERATURE °F
80
70
60
50
40
JUNE 11-17
JUNE 18-24
JUNE JULY 25-1
JULY 2-8
JULY 9-15
JULY 16-22
JULY 23-29
JULY AUG 30-5
AUG 6-12
AUG 13-19
AUG 20-26
AUG SEPT 27-2
SEPT 3-9
SEPT 10-16
1950

Fig. 25

were not dominated by the cooler ground water. Such a condition was accentuated by the reoccupancy of the logging pond, below which the creek was quite warm. Yet the true magnitude of the heating here was obscured by the lack of outlet and surface temperatures for the main pond upstream.

(4) Morrison Creek

In 1948, the first year of this study, the headwater meadow of Morrison Creek was not impounded by the beaver as it had been at least twice previously in the past score of years. The stream was flowing steadily and fed by many springs but in this open, exposed stretch it was warmed above what it had been in the cool upstream swamps. On July 27th, when afternoon air temperatures were in the high 60's (°F), the water at intervals downstream to the uppermost blown-out dam was 54°, 61°, 71°, and 68°F. When the new rebuilt structure was appraised September 3rd, shortly after its completion, the stream here at 4:30 p.m. was only 66° while the air was 78°F.

The surface waters of the uppermost impoundment became hot indeed in 1949 and 1950. This heating extended downward at least 1.5 feet in the lower end of the pond. Spot readings through each summer indicated favorable temperatures for brook trout in the upper areas of the pond, to which the fish retreated from the undue warming downstream, and where they were concentrated for the anglers, particularly during the heat of 1949. On the other hand, the available habitat was much greater the next year when the fishermen, especially those who did not know the pond, reportedly had a more difficult time in catching trout.

A series of 18 maximum-minimum thermometer figures up the length of the mile-long flowage during the summer of 1950 provided a detailed measure of thermal stratification (Table 8). These readings were taken on the third day of a hot spell when the blue sky was above lazily drifting clouds borne by a shifting wind.

Differences between the surface and depths of three and four feet ranged from 5° to as much as 20°F., and had a mean of 11.5°F. Most of these were accounted for in the upper two feet rather than further down. Water from springs and tributaries showed very strikingly, but its effect was surprisingly local. Only the most downstream of the figures at two feet was unfavorable for brook trout, and temperature did not appear to be a limiting factor in this pond very often during the cooler summer of 1950, except for its most downstream reaches. It is recognized, however, that greater extremes may have occurred later in the afternoon.

The probability that temperature was a limiting factor for brook trout in the lowermost part of the upper Morrison impoundment was evidenced by the only thermally induced fish

Table 8. Thermal Profile of Upper Morrison Creek Pond,
July 27, 1950.
(Temperatures are in degrees Fahrenheit, and the locations progress upstream through the flowage.)

| Location | Time | Air temp. | Surface | Difference | Two feet | Difference | Four feet | Total difference |
|---|---|---|---|---|---|---|---|---|
| Aldered dam above main | 2:20 p.m. | 70 | 78 | 2 | 76 | 5 | 71 | 7 |
| Blown-out dam | 2:30 p.m. | 70 | 78 | 77 | 71 | 4 | 67 | 11 |
| Off abandoned lodge | 2:35 p.m. | 73 | 79 | 11 | 69 | 1 | 68 | 11 |
| Next bend upstream | 2:40 p.m. | 72 | 80 | 8 | 72 | 2 | 70 | 10 |
| Swamp hole below blind | 2:45 p.m. | 72 | 80 | 9 | 71 | 1 | 70 | 10 |
| Upstream by duck blind | 2:50 p.m. | 73 | 78 | 7 | 71 | 2 | 69 | 9 |
| Off old cabins | 3:00 p.m. | 78 | 80 | 10 | 70 | 4 | 66 | 14 |
| Tributary from east | 3:10 p.m. | 72 | 78 | 9 | 69 | 11 | 58 | 20 |
| Next bend upstream | 3:15 p.m. | 70 | 80 | 9 | 71 | 3 | 68 | 12 |
| Off boat landing | 3:25 p.m. | 71 | 78 | 10 | 68 | 1 | 67 | 11 |
| Half-way to first spring | 3:30 p.m. | 76 | 80 | 12 | 68 | 3 | 65 | 15 |
| Off first spring hole | 3:35 p.m. | 69 | 76 | 10 | 66 | 5 | 61 | 15 |
| | | | | | | | Three feet | |
| In first spring hole | 3:40 p.m. | 72 | 77 | 11 | 66 | 6 | 60 | 17 |
| Upper end, first oxbow | 3:45 p.m. | 68 | 70 | 5 | 65 | 1 | 64 | 6 |
| First spawning redd | 3:55 p.m. | 72 | 70 | 6 | 64 | +1 | 65 | 5 |
| Off second spring hole | 4:00 p.m. | 74 | 73 | 5 | 68 | - | .. | 5 |
| Outer second spring | 4:05 p.m. | 71 | 74 | 4 | 70 | 6 | 64 | 10 |
| Inner second spring | 4:10 p.m. | 71 | 78 | 15 | 63 | 2 | 61 | 17 |
| Mean | | 71.2 | 77.0 | 8.1 | 68.9 | 3.4 | 65.5 | 11.5 |
| Ranges | | 68 - 78 | 70 - 80 | 2 - 15 | 63 - 76 | 1 - 11 | 58 - 71 | 5 - 20 |

mortality which occurred during this study. On the afternoon of July 20, 1950, 30 legal-size hatchery rainbow trout were stocked about one-third the distance up this flowage. A week later two dead creek chubs, 3 and 7 inches long, were found midway between the main dam and the old blown-out structure. The next afternoon there was a dead rainbow at the west end of the former; it apparently had died a few days earlier. Two more of this species were retrieved the morning of the 29th, and a fourth on August 1st; they ranged from 7.2 to 8.9 inches in length. No external injury was evident, but since both minnows and trout had been found, I concluded that an ecological factor, probably thermally regulated, was responsible. At least some of the rainbows could have moved into the upstream reaches which were tolerable. During the week between the stocking of these fish and the observation of mortality, temperatures in the lower part of the flowage were as high as 78° F.

Thermal records for the foregoing impoundment and the waters downstream came from four maximum-minimum thermometers in position along Morrison Creek during the field seasons of 1949 and 1950: Station A, the main pond 1.5 feet below the surface at the edge of the large blown-out dam 40 yards above the re-occupied impounding structure; Station B, its outlet six inches below the surface; Station C, opposite Lodge III, the inlet for the lower set of recently abandoned ponds; and Station D, the outlet from this area.

Temperatures in the uppermost Morrison pond were critical for brook trout during 11 weeks of 1949, being in the 80's during six of these, with a maximum of 83°F. registered twice (Table 9). The next summer was not as severe, and the highest reading was two degrees less (Table 10). Warming during eight of the 15 weeks of record created unfavorable conditions for the favored game fish, and in three of these periods it amounted to 80°F. or more.

In passing over and/or through the main dam to the outlet (Station B) the water cooled as much as 3°F. in 1949, when the mean change for the summer was a decline of almost one degree. The next season produced virtually no such change, however. The number of critical weeks was the same both years in outlet and pond, but temperatures in the 80's occurred only half as often the first summer.

From Station B downstream to C the creek flowed through unshaded abandoned ponds. The uppermost of this defunct series was reoccupied by beaver early in July of the second summer. Until this rebuilding took place, the water had warmed consistently in its passage through this stretch, but thereafter in 1950, there was a small effect of cooling. Over the preceding year the maximum temperature had five times risen two degrees and once three degrees between these stations, for which the mean increase was 0.9°F. In 1950, however, the two contrasting influences almost balanced, but here again eight weeks were critical, three of which were

Table 9. Weekly Water Temperature Ranges and Changes between Stations, Morrison Creek, 1949.

| Week beginning | Sta. A (upper pond) | Change in maxima | Sta. B (upper outlet) | Change in maxima | Sta. CC (Lodge III) | Change in maxima | Sta. D (lower outlet) | Overall change (maxima) |
|---|---|---|---|---|---|---|---|---|
| | LOCATION AND TEMPERATURE (°F.) | | | | | | | |
| June 5 | 75* - 57 | 0 | 75 - 53 | +3† | 78 - 54 | +4† | 82 - 52 | +7† |
| June 12 | 80 - 58 | -1 | 79 - 60 | +2 | 81 - 60 | +3 | 84† - 58 | +4 |
| June 19 | 75 - 63 | 0 | 75 - 63 | +1 | 76 - 62 | +1 | 77 - 62 | +2 |
| June 26 | 80 - 65 | -1 | 79 - 65 | -1 | 78 - 62 | +3 | 81 - 62 | +1 |
| July 3 | 83† - 61 | 0 | 83† - 62 | -1 | 82† - 62 | +1 | 83 - 62 | 0 |
| July 10 | 76 - 64 | -2 | 74 - 65 | +2 | 76 - 62 | +3 | 79 - 61 | +3 |
| July 17 | 80 - 64 | -1 | 79 - 64 | +1 | 80 - 60 | +2 | 82 - 58 | +2 |
| July 29 | 83† - 64 | -3† | 80 - 65 | +2 | 82† - 65 | +1 | 83 - 65 | 0 |
| July 31 | 75 - 63 | 0 | 75 - 63 | +2 | 77 - 60 | +3 | 80 - 60 | +5 |
| Aug. 7 | 82 - 65 | -2 | 80 - 68 | +2 | 82† - 64 | +2 | 84† - 64 | +2 |
| Aug. 14 | 77 - 64 | -1 | 76 - 66 | +1 | 77 - 60 | +2 | 79 - 60 | +2 |
| Aug. 21 | 72 - 64 | -1 | 71 - 64 | -1 | 70 - 59 | +2 | 72 - 57 | 0 |
| Aug. 28 | 74 - 56 | +1 | 75 - 57 | 0 | 75 - 53 | +3 | 78 - 53 | +4 |
| Sept. 4 | 66 - 54 | -1 | 65 - 53 | +1 | 66 - 50 | +2 | 68 - 50 | +2 |
| Sept. 11 | 62 - 55 | 0 | 62 - 58 | 0 | 62 - 52 | +2 | 64 - 52 | +2 |
| Mean change, 14 weeks | | -0.8 | | +0.9 | | +2.3 | | +2.4 |
| Number critical weeks | 11 | | 11 | | 12 | | 12 | |

* Critical temperatures(> 75°F.) underlined.

† Maximum weekly figure.

Table 10. Weekly Water Temperature Ranges and Changes between Stations, on Morrison Creek, 1950.

| | LOCATION AND TEMPERATURE (°F.) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Week beginning | Sta. A (upper pond) | Change in maxima | Sta. B (upper outlet) | Change in maxima | Sta. C (Lodge III) | Change in maxima | Sta. D (lower outlet) | Overall change (maxima) |
| June 4 | 78* - 54 | +1 | 79 - 59 | +1 | 80 - 52 | +2 | 82 - 51 | +4† |
| June 11 | 78 - 56 | 0 | 78 - 59 | +1 | 79 - 54 | +1 | 80 - 53 | +2 |
| June 18 | 76 - 57 | 0 | 76 - 60 | +2 | 78 - 55 | +2 | 80 - 54 | +4† |
| June 25 | 80 - 55 | 0 | 80† - 57 | +2 | 82† - 57 | +1 | 83† - 54 | +3 |
| July 2 | 72 - 55 | 0 | 72 - 57 | +1 | 73 - 56 | +1 | 74 - 59 | +2 |
| July 9 | 79 - 58 | -1 | 78 - 60 | -1 | 77 - 59 | +1 | 78 - 57 | -1 |
| July 16 | 74 - 60 | 0 | 74 - 63 | 0 | 74 - 60 | +2 | 76 - 58 | +2 |
| July 23 | 78 - 62 | 0 | 78 - 61 | -2 | 76 - 62 | +2 | 78 - 60 | 0 |
| July 30 | 80 - 53 | 0 | 80† - 56 | 0 | 80 - 56 | +1 | 81 - 54 | +1 |
| Aug. 6 | 81† - 60 | -1 | 80† - 60 | -1 | 79 - 60 | +3 | 82 - 58 | +1 |
| Aug. 13 | 73 - 62 | +1 | 74 - 63 | -2 | 72 - 60 | +4† | 76 - 50 | +3 |
| Aug. 20 | 70 - 53 | 0 | 70 - 54 | +1 | 71 - 52 | 0 | 71 - 50 | +1 |
| Aug. 27 | 70 - 58 | 0 | 70 - 56 | 0 | 70 - 56 | +1 | 71 - 54 | +1 |
| Sept. 3 | 68 - 56 | +1 | 69 - 56 | -1 | 68 - 54 | +2 | 70 - 53 | +2 |
| Sept. 10 | 68 - 53 | 0 | 68 - 54 | 0 | 68 - 53 | +2 | 70 - 52 | +2 |
| Mean change, 14 weeks. | | +0.1 | | +0.1 | | +1.7 | | +1.8 |
| Number critical weeks. | 8 | | 8 | | 8 | | 10 | |

* Critical temperatures (>75°F.) underlined.
† Maximum weekly figure.

80°F. or above. The stream had risen to 82°F. three times in the previous summer, when 12 periods had been unfavorable for trout, five of which had produced temperatures in the 80's.

Highest temperatures were evident in the lowermost reaches of beaver activity on the Morrison: from Lodge III to the lowest dam of the series. Here the rise was as much as 4°F. each summer to reach highs of 84°F. twice in 1949, and 83°F. once the next year. Two-thirds of the 12 weeks of temperatures unfavorable to trout in 1949 were 80°F. or worse, a condition which occurred six out of ten times the next season. The mean rises were 2.3 and 1.7°F. respectively.

The overall change through the four maximum-minimum stations was one of tempering in the stream's passage over the main upper dam, succeeded by accentuations of the warming as the creek coursed through the lower abandoned beaver ponds (Figure 26). The greatest net change from the upper flowage down to the county road crossing was 7°F. in 1949 (mean = 2.4°F.), and 4°F. the next year (mean = 1.8°F.), a figure which had been equalled or exceeded four times during the previous summer. Yet 14 spot temperature checks in 1948 showed local cooling from Dam II to lower stations around Dam I and the road bridge. The mean of these was a loss of 2.1°F., and the greatest tempering effect was 14°F., although there was a rise of ten degrees on another occasion. From my knowledge of the Pond I site in 1947, the summer before this was im-

Figure 26. Weekly Water Temperature Ranges, Morrison Creek, 1949 and 1950. Left to right: Station A - upper pond (broken line), Station B - upper outlet (solid line), Station C - Lodge III (broken line), and Station D - lower outlet (solid line.)

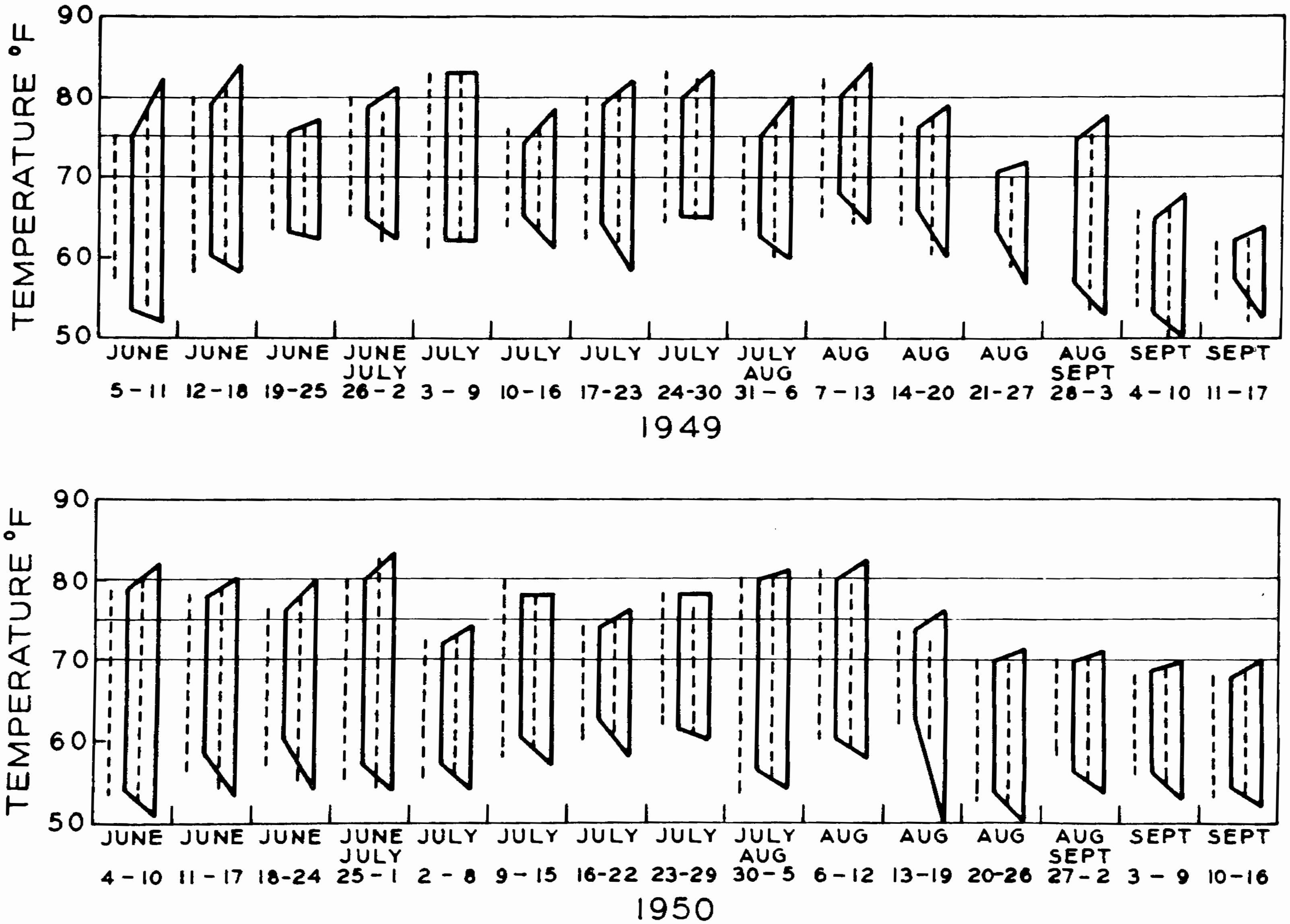

TEMPERATURE °F
90
80
70
60
50
JUNE 5-11
JUNE 12-18
JUNE 19-25
JUNE JULY 26-2
JULY 3-9
JULY 10-16
JULY 17-23
JULY 24-30
JULY AUG 31-6
AUG 7-13
AUG 14-20
AUG 21-27
AUG SEPT 28-3
SEPT 4-10
SEPT 11-17
1949
TEMPERATURE °F
90
80
70
60
50
JUNE 4-10
JUNE 11-17
JUNE 18-24
JUNE JULY 25-1
JULY 2-8
JULY 9-15
JULY 16-22
JULY 23-29
JULY AUG 30-5
AUG 6-12
AUG 13-19
AUG 20-26
AUG SEPT 27-2
SEPT 3-9
SEPT 10-16
1950

Fig. 26

pounded, the creek here received several springs. Could it be that under certain weather conditions this cool water had a more lasting effect on the bottom of a beaver pond than when it was aerated and mixed in a natural flowing stream? Such a phenomenon would also account for the creek's temperature as it was influenced upstream both by the new middle pond in 1950, and by the main upper pond when it was stratified both summers.

The predominant thermal change in the downstream reaches of Morrison Creek which had been formerly occupied by beaver was a warming one, the severest of all those under intensive observation. This was similar to the situation through the abandoned lower flowages on the East Branch of Bluff Creek, where too there was an absolute lack of shade, and the affluents were soon heated. However, in the Bluff the temperature recovered downstream from the area of beaver occupancy. Morrison Creek, however, warmed its recipient, the Middle Branch of the Ontonagon River, rather than cooling it, as most feeders are presumed to do.

## B. Findings of Other Investigators

Biologists elsewhere in the nation have noted the warming effects of beaver ponds in raising the temperatures of trout streams, which may be either beneficial or harmful (Hubbs, Greeley, and Tarzwell, 1932). Although the summer heating of the impoundments is generally regarded as the most serious thermal manifestation of beaver occupancy on the favored game fishes, Salyer (1935-a) held that autumnal cooling to temperatures below the spawning threshold of brook trout often severely interfered with their natural reproduction. Winter conditions in Alaska can be quite precarious for fish residents of beaver impoundments of the Fairbanks area, where 30 inches of depth were necessary to prevent freeze-outs (Hakala, 1952).

Several men have pointed out the differences between the summer warming in narrow and confined, deep ponds as opposed to that in wide, shallow flowages (Greene, Hunter, and Senning, 1932). The former occur particularly in mountain regions with steep stream gradients, which may have accounted for the absence of significant temperature variations above, within, and below a series of impoundments in West Virginia (Swasey, 1948). Much the same conditions are present in western United States: warming is seldom severe enough to affect trout populations adversely, and what little does occur is regarded as beneficial. Rasmussen (1941) found no great rises in temperature on streams occupied by beaver in the Rockies of Utah, where the average size pond was only 0.3 of an acre, and stream gradient had a mean of 115 feet per mile. Trout stocking in Glacier National Park was more successful in waters which had been warmed somewhat by the ponds of these animals than it was in those systems from which beaver were absent (Hazzard, 1933).

An unusual observation in northern Wisconsin demonstrated that impoundments, by deepening the water, could aid fish survival in rocky reaches which would otherwise have been shallow and hot (Couch, 1936). Salyer too (1935-a) recognized this beneficial effect for Michigan streams tributary to Lake Superior, and such conditions might also occur in the Tamarack River headwaters east of Watersmeet in Gogebic County.

Whereas the western mountain streams are generally improved for trout by beaver occupancy, the warming in the less rugged terrain of eastern United States is definitely harmful, according to Tarzwell (ms.) and Reid (1951). The heating is due to several factors, which include the slow flow of the stream, the wide spread of the water, and the destruction of shade trees (Patterson, 1951-a). Salyer (1934) realized that these various elements should be considered in an overall evaluation, but the numerous Gladwin refuge temperature figures of Bradt (1934) are difficult to appraise without a good knowledge of his study area as it was two decades ago.

However, Evans (ms.) demonstrated conclusive warming in the North Shore streams of Minnesota which flow into Lake Superior. Some of these became hotter than 75°F., and others surpassed the temperature of optimum brook trout growth (68°F.). His later report (1948) on the same work showed consistent rises from the inlets to the outlets of several ponds, in which thermal stratification was as great as 18°F. in seven feet of water. Little seepage through the dams occurred, and Patterson (1950-a) also found that surface temperatures governed those of the outlets from beaver impoundments in northeastern Wisconsin. Thermometer readings downstream from some Wyoming ponds were approximately equal to those one foot below the surface, according to Ballou (1950).

Salyer (1935-a) held that the warming of trout waters by beaver was only of secondary import because of the usual cooling in reaches immediately downstream from their colonies. In Minnesota Hale and Jarvenpa (1950) had similar views, but Evans (ms.) cautioned that possible harm in such stretches should be weighed against the benefits of the activities of these animals. The latter investigator (1948) correlated temperature changes along a stream with the frequencies of shaded areas and exposed impoundments, as had Greene, Hunter, and Senning (1934).

Patterson (1950-a) compared temperatures on streams with and without beaver dams and found those of the former to be considerably higher. According to him (1951-a), tributaries of the latter sort served to cool larger waters from the warming effects of ponds elsewhere in the drainages. The import of cold feeders to a main stream had earlier been recognized by Tarzwell (ms.) for the Black River in Michigan's Lower Peninsula.

A decrease in stream temperatures followed dam removal from a Penobscot River tributary in Maine (Rupp, 1953). The previous increase had not been thermally harmful to a resident brook trout population, thanks to the counteraction of numerous springs. Such sources of ground-water seepage also lessened the temperature effects of a restored impoundment in Michigan (Shetter and Whalls, 1953). The rebuilding of an abandoned beaver dam on Fuller Creek, Montmorency County did warm the stream, in the period following the reconstruction, above the temperatures of the previous three years. This study was based on average daily figures rather than the maximum temperatures, which might have been harmful to brook trout in summer.

(C) <u>Thermal Tolerances and Optimum Temperatures of Brook Trout</u>

It has been shown that trout streams become warm in their passage through beaver ponds. Before rendering judgment on this damage to the habitat, a review of the thermal tolerances of brook trout is appropriate to establish values for minimum, optimum, and maximum temperatures of its environment.

(1) Emphasis on Field Observations: Embody <u>et al</u>

Prior to the work of Embody (1921) the highest favorable temperatures for brook trout waters were regarded as 68° to 70°F., but he found that this species could be produced in ponds much warmer than previously supposed. Small New York streams as high as 77-79°F. produced good yields of brook trout, and the corresponding figures for brown and steelhead trout were 83° and 85°F. respectively. It has long been recognized that the brook trout is the weakest of the three species in its thermal tolerances, and the other two will not be considered in this appraisal, except indirectly.

During one summer Embody (1921) held a group of brook trout in a 20-by-4-foot raceway supplied with spring water. The fish were in distress and ceased feeding at 83.3°F., after which they lived through six days which ranged from 78.8° to 80.7°F. However, a 20-percent mortality occurred at 84.2°F., but there were no deaths the next day when the maximum was 82.4°F. By the time the temperature reached 83.2°F. the following day, none of the brook trout survived. He concluded from this experiment that fishery biologists had been too conservative in their estimates of temperature effects alone.

In another report, Embody (1922) suggested that the native brook trout might be gradually adapting itself to warmer waters through natural selection, and recommended that 75°F. be regarded as the threshold between trout and non-trout waters. His survey of Tompkins County in 1918 found three of these fish apparently not in distress at 81°F. in upper Van Pelt Brook; other tolerated highs ranged from 76° to 80°F. when air temperatures in the open were as much as 100°F.

In exploring the thermal tolerance of brook trout, Breder (1927) concluded that increased temperature *per se* was not a limiting factor, but that its true significance was in lowering the oxygen saturation point. He described swift shallow streams flowing through farmland in Ashe County, North Carolina, in which brook trout tolerated 80°F. water. Creaser and Brown (1927) further suggest that the final action of temperature might not be direct on trout, or even indirect through oxygen, but still more indirect in favoring the survival of competing species.

Embody (1928) determined experimentally the relationships between air and water temperatures which should not be exceeded for a stream to be considered suitable for brook trout. These were corrected for elevations above a thousand feet, and the combination served as an index of fish habitat during later biological surveys of the State of New York Conservation Department.

Creaser (1930) set the maximum for self-sustaining brook trout waters at 19°C. (66°F.). The thermal difference between favorable and unfavorable streams was considered to be very small, and a rise in one part frequently caused the trout to move elsewhere, according to him. Upstream movement when water level is declining may be a manifestation of temperature effect, and point to it as a limiting factor. For trout growth, however, high temperatures are much better than low ones.

A favorable range for brook trout between 50° and 71°F. was advanced by McGonigle (1931) on the basis of changes in rate of breathing, which increased between these two figures, but declined on either side of them. Later (1932) this worker subjected brook trout fingerlings to a one-degree Centigrade rise in temperature every five minutes. Normal, healthy fish commenced to die at 29°C. (84.2°F.) but some remained alive until a degree higher (86°F.); diseased, unhealthy individuals, however, perished in the range 22-29°C. (71.6-84.2°F.). McGonigle commented (p. 122):

> "That the changes of the trout's physiological processes may be associated with some disturbance of the nervous system, at the upper of the three ranges, seems to be shown by several observations, of which the loss of balance, the irregular, gasping breathing, the sudden darkening in color, the distress, etc. observed to become increasingly evident with rise of temperature, are some examples."

A need for more information on optimum trout temperatures was apparent to Hubbs, Greeley, and Tarzwell (1932) in their discussion of the environmental needs of this game fish. Whereas cold springs flowing at 43° to 52°F. were thought to be particularly favorable for spawning, growth was found to be much better at 60°-70°F. However, the brook trout in the cooler waters were cited as being relatively free from competition with warm-water species. Working in southern Ontario, Ricker (1934-b) selected 24°C. (75°F.) as the separation point between trout and non-trout waters. Nevertheless he expressed concern that this might prove too low when the northern brown-water streams of the province were examined. The 19°C. (66°F.) limit of Creaser (1930) would exclude many of the best trout-fishing areas in Ontario.

Locations suitable for trout culture should range between 40° and 68°F. over the year, according to Embody (1936). Optimum temperature ranges for winter and summer at such stations were defined as 47-52° and 55-60°F. respectively. Hoover (1937) established 70°F. as the average summer maximum for brook trout in New Hampshire. This figure was supported by the subsequent field survey findings of Bailey (1938).

In Indiana Murray (1938) recognized the thermal conditions as the critical criterion of trout waters rather than oxygen or carbon dioxide. He used the 75°F.-figure of Embody (1922) as the deciding factor for identifying the salmonoid habitats in the northern part of the state. Needham (1938) stressed the relation of temperature tolerance to various environmental factors, and regarded 66°F. as the ideal for brook trout in summer.

Turning again to hatcheries and stocking, losses among brook trout when 15 of 50 1.5-inch fish died on transfer from 52°- to 70°F.-water were attributed to high temperature (Hagen, 1939). This mortality was not too great, and might have been due to combined physico-chemical conditions rather than thermal effects alone, but it definitely pointed towards tempering fish before planting them.

The importance of spring water in good brook trout habitats is brought forth in a federal bulletin (Leach, 1923: p. 7) in these words:

> "The ideal brook-trout stream receives numerour spring-fed tributaries throughout its course, so that its temperature does not exceed 65°F. in summer and by the same means is maintained at a relatively high temperature during the winter months... Any stream having summer temperature greater than 65° can hardly be considered suitable for brook trout unless it has large spring tributaries accessible to the fish during the heated period. Through the cutting away of the forests and the cultivation of the land many streams in the eastern part of the United States have become unsuited to brook trout."

Cooper (1940) in his discussion of trout environmental requirements included water cooler than 75°, but better below 70°F. The latter figure he used as a maximum temperature limit for brook trout in southern Maine lakes where competing warm-water species were present, and the former for northern waters in which such fishes were absent, though he considered this as marginal.

(2) Trend towards laboratory experiments: Fry *et al*

The effect of acclimation on critical temperatures (those at which fish began to die) and lethal ones (those at which half the fish were killed in 12 hours' time) was the subject of an early investigation of the Ontario Fisheries Research Laboratory (Brett, 1941). This worker showed that critical temperatures were adjusted upward by a rise in holding or acclimation temperatures as follows:

| Acclimation Temperature | Critical Temperature |
|---|---|
| 13°C. (55.4°F.) | 21°C. (69.8°F.) |
| 16°C. (60.8°F.) | 23°C. (73.4°F.) |
| 19°C. (66.2°F.) | 24°C. (75.2°F.) |

Laboratory experiments of King (1943) showed that temperatures higher than 70°F. were required to kill fingerling brook trout. Tests of this and two other stream species had them all showing distress at 80°F., but only two rainbows died below 84°F. However, all fish were dead at 86°F. From these and his other survival tests, some of which will be examined in Chapter IV of this paper, he concluded (p. 632), "Temperature may be a limiting factor in itself and, in addition, indirectly by virtue of its influence on pH, carbon dioxide tension, the saturation point for oxygen, and food consumption."

Another experiment at Algonquin Park, Ontario (Brett, 1944) set the upper lethal temperature for brook trout as 79.0°F. (26.1°C. in Table 11) or 79.9°F. (26.6°C. in Figure 10). In their Minnesota stream survey Smith and Moyle (1944) went along with the figures of 75°F. as the upper limit of brook trout tolerance and 66°F. as the optimum temperature in accord with Needham (1938). They recognized several factors, including beaver ponds, as influencing this element of the fish habitat. Discussing the care of fingerling trout, Davis (1946) advised that 65°F. was the maximum for rearing pools, and preferably lower, with most rapid growth in the 55°-to-60°F.-range.

Clear, hot weather and low water in reaches exposed to the sun accounted for a disaster to several species of fishes, including brook trout, in New Brunswick during June of 1942. Huntsman (1946) concluded that high temperatures (minimal to 78° and maximal to 88.5°F.) and low acclimation to them were responsible for this mortality. Support for this theory came from laboratory studies of Fry, Hart, and Walker (1946), who subjected yearling hatchery brook trout to various temperature conditions, and reported (pp. 28-29):

> "A sample of five trout acclimated to 20°C. was exposed to 27°C. for three hours (60% mortification) and then returned to 20°C. for 22 hours. They were then subjected to 27°C. for five hours, the expected median mortality time, with no deaths resulting. The experiment was then discontinued for it was evident that any residual effect of the exposure on the previous day was not such as to reduce the survival time. Indeed since none of the fish had died within the expected median mortality time, there is some hint of a gain in acclimation as a result of the previous sublethal exposure."

Their ultimate upper lethal temperature, 25.3°C. (78°F.), is close to the brook trout maxima of 75°F. derived by both Embody (1922) and Ricker (1934-b), which fish culturists have generally accepted. The figures progressing to this limit, as given in Table 5, page 19, were:

| Acclimation Temperature | | Lethal Temperature | |
|---|---|---|---|
| 3°C. | (37.4°F.) | 23.4°C. | (74.1°F.) |
| 11°C. | (51.8°F.) | 24.5°C. | (76.1°F.) |
| 20°C. | (68.0°F.) | 25.3°C. | (77.5°F.) |
| 22°C. | (71.6°F.) | -- | -- |
| 24.25°C. | (75.6°F.) | 25.3°C. | (77.5°F.) |

In agreement with the observations of Elson (1942), the speckled trout of an Algonquin Park Lake moved into deep water after mid-June when the upper strata exceeded 68°F. (Baldwin, 1948). They remained there in the 54° to 68°F.-region until late August, and returned to shoal water again the next month. These temperatures include the 16° to 19°C. (60.8°-68°F.) range in which Graham (1949) found speckled trout yearlings to be most active in his laboratory experiments.

As an indication of this species' adaptability, a New Hampshire survey crew took fish in good condition from an artificial pond at depths of four to five feet in 77°-78°F.-water the oxygen content of which ranged from 3.1 to 4.0 p.p.m. (Siegler, 1948). That state's conservation agency had not recommended the stocking of brook trout in ponds warmer than 72°F., whereas the policy in Iowa was to plant hatchery fish only in streams suitable throughout the fishing season which did not rise above the generally fatal 75°F.-mark (R. B. Cooper, 1950).

In a laboratory study of growth and feeding habits of this species, Baldwin (1951) kept lots of four fish at temperatures of 9°, 13°, 17°, and 21°C. for a month and provided them with a liberal supply of minnows. Both food consumption and growth were highest at 13°C (55.4°F.), and lowest at 21°C. (69.8°F.). The fish of the latter group lost considerable weight the first week, an effect which lessened with time, but throughout the experiment they had considerable difficulty catching the minnows.

Fry (1951) evaluated both field and laboratory findings on the temperature tolerances of speckled trout. The former were summarized in statements that these fish (1) were not found in streams above 20°C. (68°F.) for extended periods; (2) survived for a short time in water at 24°C. (75°F.) and 27°C. (81°F.); (3) did not die in well-aerated ponds over 20°C. (68°F.) without competition; and (4) survived in waters warmer than this when making excursions from colder areas.

Controlled tests at the Ontario Fisheries Research Laboratory had the fish seeking warmer waters when they had been acclimated below 14°C. (57°F.), but staying put between 14° and 19°C. (57-66°F.), beyond which they sought cooler waters. He set the lethal temperature for prolonged exposure at 25.3°C. (77.5°F.), a point above which these fish had often been observed in nature. Fry pointed out again that the effect of all lethal temperature experience is summed until death, and mentioned an instance of brook trout lasting for about an hour at 28.5°C. (83.3°F.), then recovering when the water at night was less than 25°C. (77°F.).

Temperature optima, based on reaction to electric stimulus, maximum cruising speed and oxygen uptake, and optimum growth, ranged from 10° to 20°C. (50°-68°F.).

He set the warmest of these figures as the limit on good trout water, although both food supply and availability increased at higher temperatures. Fry regarded size and age differences of the fish as unimportant.

Returning to field observations, Patterson (1951-b, pp. 17-18) presented this evidence on both optimum and maximum thermal conditions for brook trout:

> "It is interesting to note that the five streams of the 26 which had the coldest water temperatures, that is from 54° to 62°, also had the most trout per unit of area. For most of the streams worked upon, the water temperature ranged between 64° and 68°. It should be mentioned that last summer was a particularly cool summer. When stream temperatures ran from 71° to 80°, trout were much more difficult to locate. At these higher temperatures even large deep pools were usually barren of trout. Then trout could sometimes be found concentrated at the mouth of cold feeder streams. A notable exception, though, is the capture of 10 legal brook trout in water of 80° temperature in the Tyler Forks River, Iron County. These trout were in excellent condition and showed no sign of distress."

D. Morrison Creek Test Fish Experiment

(1) Background

From the preceding review it seems that brook trout do best at temperatures of 66° or 68°F., but are not well off at 75°F., above which total mortality can be expected at some point below 85°F. The great variations in laboratory and field findings throughout the range of this fish may indicate the existence of various "races" with different environmental tolerances as suggested some twenty years ago by Hubbs, Greeley, and Targwell (1932, p. 14):

> "How warm a trout stream can become, for each trout species, has been much debated. There is good reason to believe that this critical point varies greatly, depending not only upon the species of trout, but also upon its race, and upon the individual fish, and also, very decidedly, upon the purity of the water and upon its dissolved oxygen content. This variability in temperature resistance adds greatly to the complexity of trout stream survey work. Whether trout will do well in stream water warming to above 70°F. in peak temperatures depends not only on the factors listed above, but also on the degree of disease infection and of competition from chubs and shiners, or from such lake fish as pike, perch and bass.
>
> "The upper limit of temperature-tolerance by trout in nature occurs therefore in clean, well-aerated streams not subject to extremes of competition, predation or disease. We have found brook trout in Michigan freely rising to the fly in such a stream, when and where the pool temperatures were 75°F. Peak temperature readings of 81° and 82°F. were obtained in 1931 in certain Michigan streams in which the trout were common and healthy, verifying observations by Embody in New York."

Before I began field operations, A. M. Stebler, then director of the Cusino Wildlife Experiment Station, reiterated to me the need to determine tolerances of native Michigan fish to temperature, oxygen and pH. He considered the demonstration angle as important as the actual experiment in this case, and advised that this particular project should aim to establish minimum, optimum, and maximum figures of these three important environmental influences.

A practical test of this nature was carried out for temperature in 1950 on Morrison Creek just above the bridge of old highway U.S.-2. Lack of a recording thermograph occasioned the delay in this phase of the study until that year. During the previous summers high water temperatures had been noted several times, but their durations were not known. In fact, even getting the maximum reading for the day with only a pocket thermometer would have been difficult. Ricker (1934-b) had found the Mad River in Ontario at its warmest between 4:30 and 6:00 p.m. and coolest from 7:00 until 9:00 a.m.; and Rainwater (1937), from hourly figures on Moose Brook in New Hampshire's White Mountains, had noted maxima of both air and water at 3:00 p.m. The difficulties stemming from spot temperature readings as an index of the suitability of waters for trout were thus outlined by Murray (1938, pp. 89-90):

> "From the standpoint of trout culture it is of prime importance to know the maximum temperature reached by the stream, even though this temperature occurs only once in the summer. It is also important to know the duration of temperatures approaching the maximum. To get such data, without self-recording thermometers, on streams in eight counties is not an easy task. The work is further complicated by the fact, that as noted above, a great many factors influence the heating of a particular stream, so that it is necessary to examine an individual stream at several places. Obviously, our records are thus only approximations of the true maximum temperature, although in some cases very close to it."

(2) Procedure

The thermograph used in connection with the stream tests of brook trout thermal tolerance was a clock-driven

Model 1100 of the Friez Instrument Division, Bendix Aviation Corporation. It consisted of a thermocouple, cable, recording pen, and graph calibrated in two-degree F.-divisions. The primary element was submerged in a foot of water on a mud bottom along the margin of the stream two feet upstream from a cage for holding the experimental trout. Pocket thermometers had revealed no spring flow in the vicinity, a check which was repeated from time to time; and there was a maximum-minimum instrument attached to a log on the opposite shore.

During the previous field seasons, the water here had reached 80°F., and Pond I had always been amply supplied with oxygen over the preceding two summers. Thus temperature seemed to be the only environmental factor which would here be harmful to brook trout. Morrison Creek fluctuated in height and flow with heavy rains and dry weather, but at no time was the fish cage stranded or overtopped.

A fish collection the afternoon of July 3, 1950, showed the reach from the Middle Branch of the Ontonagon River to the old Dam I to contain typical species of marginal trout streams in this area, of which the following were taken from the 58°F.-water (air: 56°F.) with a direct-current fish shocker:

| Name | Number | Size range |
|---|---|---|
| Brook trout | 5 | 1.8, 1.9, 3.5, 6.2, 6.7 inches |
| White sucker | 25 | 1-inch fry |
| Creek chub | 10 | 2-5 inches |
| Pearl dace | 3 | 2 inches |
| Blacknose dace | 21 | 2-3 1/2 inches |
| Mudminnow | 3 | 2-4 inches |
| Johnny darter | 2 | 2 1/2 inches |
| Northern muddler | 1 | 3 inches |
| Brook stickleback | 2 | 1 1/2 inches |

For the experiment I decided to use native brook trout of sub-legal and fingerling size; Michigan's legal-length hatchery fish in 1950 were not marked at all, and the former category was the largest which would assure natural reproduction. Accordingly five trout were collected from the Middle Branch of the Ontonagon River the afternoon of July 6th, and transferred from this water at 64°F. to that of Morrison Creek, which was ten degrees warmer. The sizes of these fish were: 2.2, 2.3, 5.1, 5.1, and 6.4 inches and they all appeared normal and in good health on external examination.

The trout were placed in a wire cage which had been set in a hole by the west shore of the creek (Figure 27). Here the depth ranged from 24 to 30 inches, and there was at least a small current at all times. The enclosure was 30 inches long, the same in height, and 18 inches wide; the ends were of quarter-inch mesh screen, the sides, bottom and top of eighth-inch wire sheeting. The wooden frame was supported by four corner posts of 2-by-4's, which were driven into the sandy stream bottom, and the cage was kept locked.

Figure 27. Morrison Creek test fish cage, summer of 1950.

Fig. 27

Although chance drift organisms might have been sufficient nutriment, the caged trout were provided a slight amount of hatchery diet every other morning when they were inspected. Two pieces of alder root stumps afforded them cover, and there were also three rocks in the bottom of the enclosure. During the daily routine check the wire cage was brushed free of the debris which had accumulated, and extra trips for this purpose were made following severe rains until the experiment was terminated September 21st.

(3) Findings and Interpretation

The only mortalities among the five brook trout in the enclosure came within the first fortnight of the experiment. Following two days of water temperatures as warm as 79° and 80°F. respectively, one of the 5.1-inch fish succumbed on July 12th, when the largest of the five was also in distress. The latter did not survive until the next day despite the lower maximum of 74°F. and a slight rainfall. Over July 10th and 11th the trout had been in water warmer than 75°F. for eight hours or more, and in the four preceding days they had had a chance to become acclimated.

Investigations at the Ontario Fisheries Research Laboratory have shown that survival through successive hot periods tends to strengthen rather than weaken a fish's tolerance to extremes of temperature. According to the standards of Fry, Hart, and Walker (1946), the loss of these two trout within the first six days of my experiment was not due to the warming of their environment. The autopsies of these individuals did not show the specific cause of death, for which the heat effect evidently does not have definitive physiological manifestations. It could be that the change from open river to the confined enclosure brought about something which might be called cage fright in the two individuals which did not survive, and that they exhausted themselves seeking a means of escape.

Two subsequent periods of excessive temperature did not bring death to any of the three remaining trout (Figure 28). These occasions brought the water to 81° and 81.5°F. on two days late in July, and as high as 83°F. twice within 48 hours during early August. Temperatures over 80°F. prevailed at most for 5.5 hours of a day, a condition which was not lethal for such a short time. This survival agreed with the laboratory experiments of Fry, Hart, and Walker when deriving the percentage mortality on the basis of the experience revealed in the actual thermograph record for the worst day of the summer (Ibid., figs. 4 and 6).

Only three periods appear critical for brook trout survival because of unfavorable thermal conditions (Figure 28), whereas a fourth one which might have been expected August 15th-17th was nullified by heavy rainfall (Figure 29). Precipitation ended each of the most unfavorable situations

Figure 28. Distribution and extent of periods of unfavorable temperatures for brook trout in Morrison Creek test fish experiment, 1950.

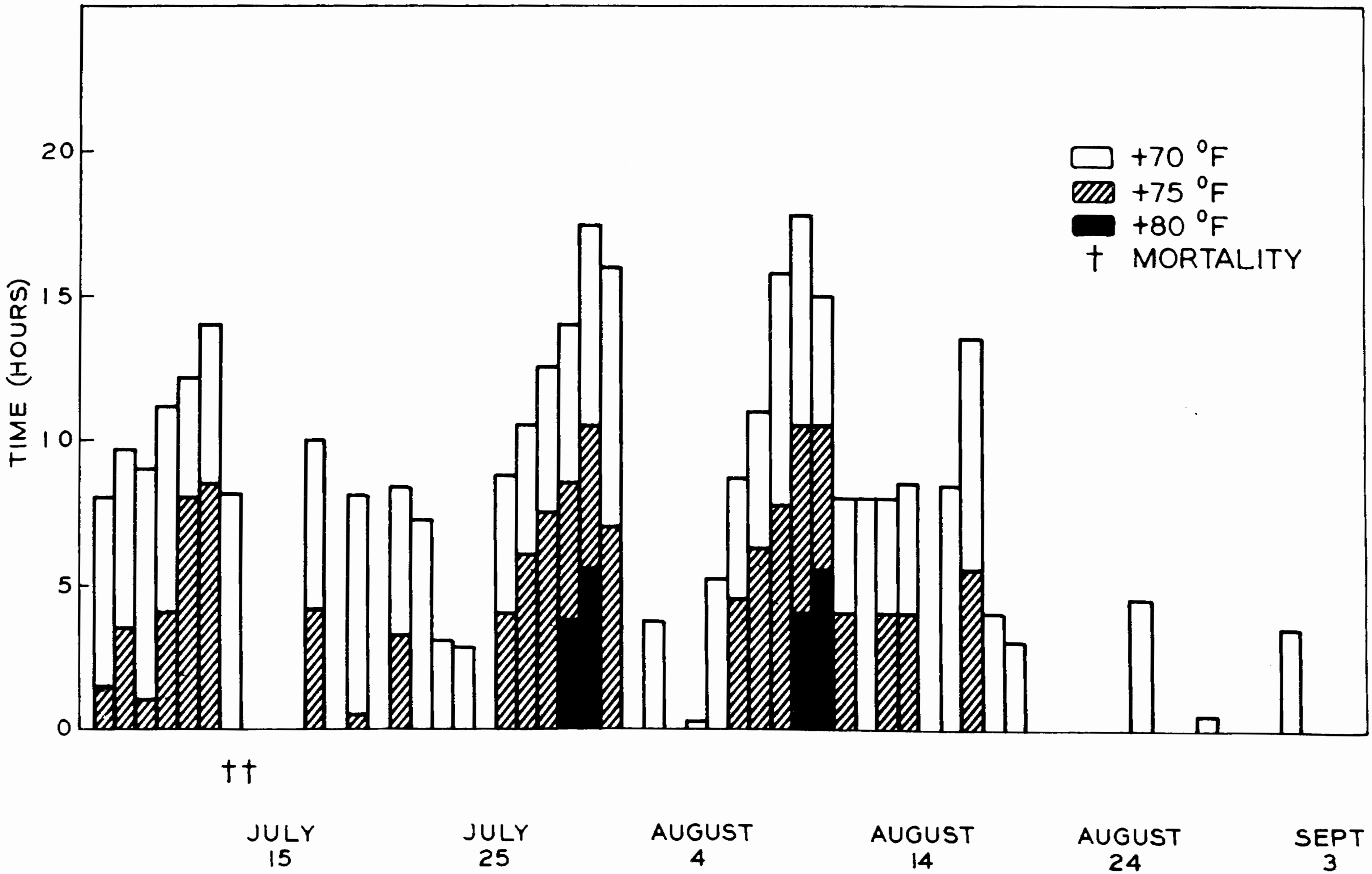

TIME (HOURS)
20
15
10
5
0
+70 °F
+75 °F
+80 °F
† MORTALITY
††
JULY 15
JULY 25
AUGUST 4
AUGUST 14
AUGUST 24
SEPT 3

Fig. 28

Figure 29. Meteorological conditions, Morrison Creek test fish experiment, 1950 (Water temperatures from recording thermograph, air temperature and precipitation from U. S. Forest Service).

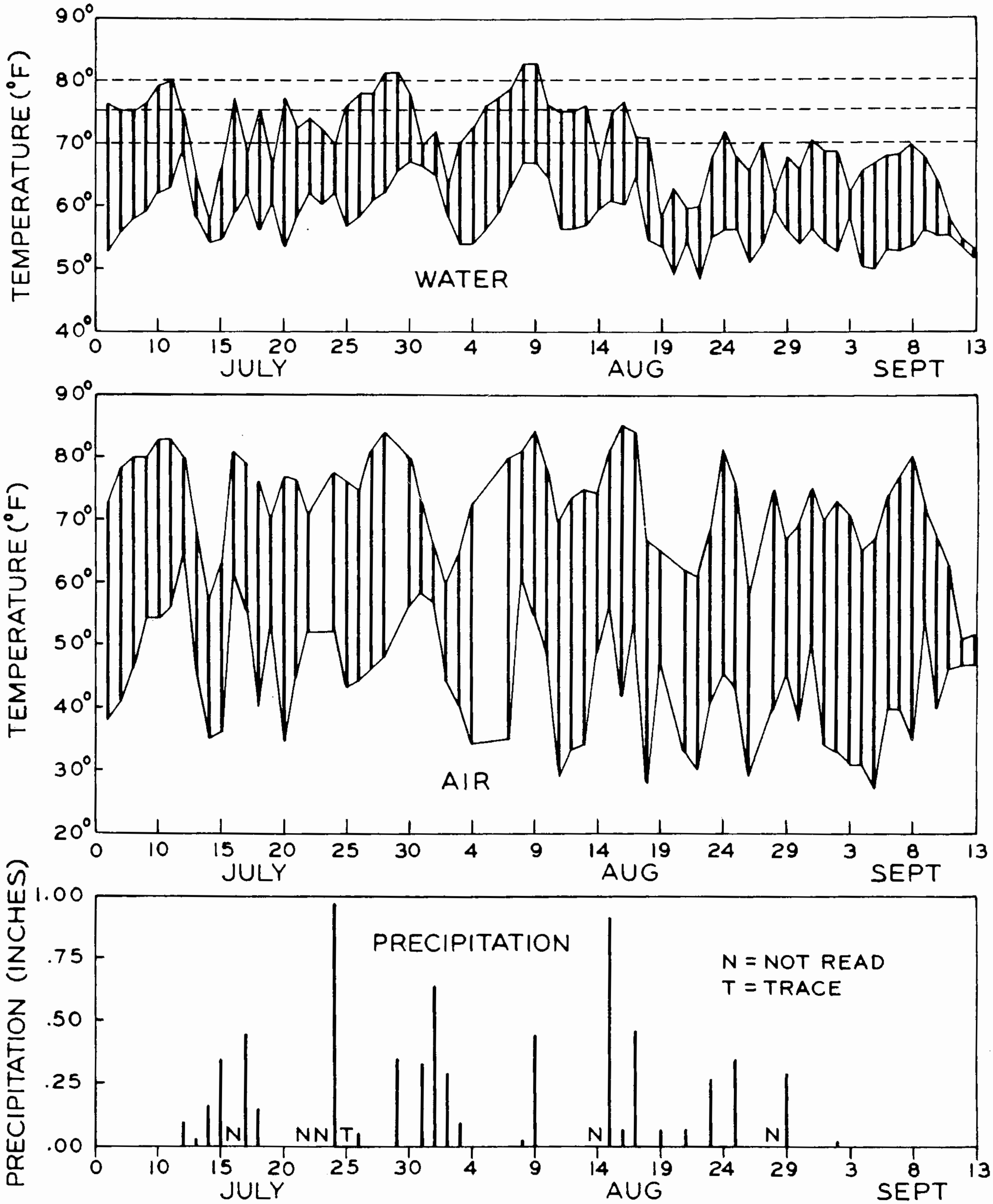

90°
80°
70°
60°
50°
40°
TEMPERATURE (°F)
WATER
0 10 15 20 25 30 4 9 14 19 24 29 3 8 13
JULY
AUG
SEPT
90°
80°
70°
60°
50°
40°
30°
20°
TEMPERATURE (°F)
AIR
0 10 15 20 25 30 4 9 14 19 24 29 3 8 13
JULY
AUG
SEPT
1.00
.75
.50
.25
.00
PRECIPITATION (INCHES)
PRECIPITATION
N = NOT READ
T = TRACE
N
NN
T
N
N
0 10 15 20 25 30 4 9 14 19 24 29 3 8 13
JULY
AUG
SEPT

Fig. 29

which, if prolonged, might have brought additional mortality. One brook trout appeared weak on August 8th, but did not succumb.

From the above events when native Michigan brook trout were acclimated and then subjected to natural extreme warming, it appears that such fish are able to withstand temperatures greater than 70°F. for 17.5 hours, above 75°F. for 10.5 hours, and between 80° and 83°F. for 5.5 hours, provided the water at night cools to at least 67°F. and there is an ample supply of oxygen. The import of acclimation, the nocturnal thermal change in the opposite direction, and adequate oxygen saturation must be borne in mind as factors probably enabling such survival. These were not subject to control in a natural environment such as Morrison Creek, but could be altered in the laboratory. The fish were spoon-fed and free from competition, an advantage which would not be theirs in the usual habitat where other species might well have superiority over them both in range or territory, and in foraging.

The trout which survived this experiment grew from lengths of 5.1, 2.3, and 2.2 inches to 7.1, 3.5, and 3.2 inches respectively. Four mudminnows had been enclosed with them, two of which died early in August when no attempt was made to postulate the cause of their demise, and a third had perished along with the two brook trout in mid-July. On four occasions native fish of the latter species appeared near the cage in the morning, but probably retreated to cooler water in either direction during the hours of intense warming. Also schools of blacknose dace took advantage of the opportunities to get free meals from the excess hatchery feed as it was brushed off the screening of the cage.

The brook trout probably were not at ease at the temperatures over 75°F., which they tolerated under the above conditions. Competitive relations of the brook trout are not well understood, a point to be emphasized in a later report. This experiment ran through only part of a relatively cool summer and is well worth repeating on other streams which may be marginal at times. I am convinced that wild fish are more hardy than hatchery ones and feel that while the present thermal criteria of trout stream management apply very well to the latter, various races and strains of native brook trout may be better able to withstand extremes of temperature than other wild fish or artificially reared ones.

## E. Evaluation of Beaver Ponds as Influences upon Trout Stream Temperatures

Among the environmental factors acting on trout stream temperatures, as listed by Rainwater (1937), are marginal cover, tributaries, dams, insolation, and rainfall. He commented thus on additional items which should be considered (p. 127):

"Other factors such as humidity, altitude, type of stream bottom, rate of evaporation, local thunder storms and seasonal variation of the size of the stream bed are undoubtedly of importance and investigations are needed to ascertain their effect upon water temperatures. More marginal streams might be brought into production if we better understood conditions which affect them."

Forests generally have more influence on fish through temperature relations than because of organic substances in solution, or the liberation of carbon dioxide from them (Creaser, 1930). From a study of the Carbondale River in Alberta, Cormack (1949) concluded that virgin timber provided the best arrangement of vegetation to shade trout streams. This included tall trees, small ones, and shrubs, of which the last, plus willow and alder, were held to be much less effective than a scattering of tall spruces. Undisturbed forest in July bordered water averaging 47°F., while beaver ponds in this dominantly coniferous cover averaged 53°F.

The increased water temperatures of the impoundments were brought about by a combination of factors: streams were spread out over a shallow area in which the trees which formerly shaded it had been killed, and the black organic bottom material may be presumed to absorb more heat than the original light-colored sand or gravel substrate. The diurnal cycle of rising and falling temperatures was a pronounced one, maximum figures coming late in the afternoon shortly before sunset and the minima early in the morning before the sun struck the surface of the pond. The duration of these effects depended upon various meteorolgical factors (Figures 28 and 29), as it does in a stream of any sort; and an impoundment at night is probably cooled from both top and bottom.

The warming of water characteristic of beaver ponds was much greater in wide, shallow ones (upper Morrison Creek) than in deep ones confined between ridges (lower Morrison Creek and headwaters of Bluff Creek). The overall effect of a large flowage (upper Morrison Creek) was comparable to that of several small dams (headwaters of Bluff Creek), and in each category the water became progressively warmer as it approached the dams. Other factors which influenced this thermal result were the stream gradient, the volume of flow, and the amount of spring water which entered the pond and its affluent. Heating of beaver impoundments in flat terrain (upper Morrison Creek) was much more pronounced than in hilly areas (headwaters of Bluff Creek) and was less on a large stream (Middle Branch of the Ontonagon River) than on small feeders (Morrison and McGinty creeks).

Although the major part of a pond may not be favorable for brook trout, they were found to be attracted to the areas of spring seepage within such bodies of water (upper Morrison Creek) to which they retreated during the periods of most unfavorable heating. This situation is similar to that in large natural lakes as described by Odell (1932, p. 332), "In shallow lakes where the water temperatures are high in general, the speckled trout are found either off the mouths of cold brooks or in spring holes." The behavior of the fish populations in my Upper Peninsula study areas will be discussed at length in another report.

Thermal stratification was definitely established in spring-fed beaver ponds (upper Morrison Creek and headwaters of Bluff Creek) and was comparable to that described for Kettle Creek Recreation Park Dam and natural pools along that Pennsylvania stream by Watts, Trembley and Harvey (1942: Table 7, p. 23). Temperature layering of water permitted the survival of brook trout in the flooded creek channels and was similar to the cold-water density current described by Borges (1950) for the Niangua Arm of the Lake of the Ozarks, Missouri, which was attractive to white bass during an intense stagnation period of July and August.

The warmer layer on top of the beaver ponds dominated the outlet temperature of older dams, whereas there was considerable seepage through both newer structures and those whose breaks had subsequently been plugged by the beaver. The cooling of such surface waters in passing over a dam was evidently more marked at night than during the hot days. To gain an overall picture of any outlet temperature, thermometer readings of this flow, the surface, and the bottom of the pond should be taken along the structure at five-yard intervals, a consideration which came to my mind, but was not followed through in the field.

The heating effect of beaver ponds on their affluents may or may not be nullified or reduced in importance for trout downstream (Bluff Creek *vs.* Morrison Creek), depending upon the amount of shade, volume of the ground-water contribution and the steepness of stream gradient. These were favorable in the former location, but not in the latter, where damage to the first factor was due to intensive beaver occupancy of the lower reaches, an effect also incurred on a short stretch of the other creek too, but there it was definitely overcome further downstream rather than being accentuated.

From the above consideration regarding temperature effects in western upper Michigan, the beaver population should be discouraged on short feeder creeks of low gradient, particularly those which have wide lowlands and are not confined between ridges, if these waters are to be managed primarily for trout. The animals are not unduly harmful on long tributaries of moderate gradient, provided that the downstream shade is not destroyed by the beaver themselves or by influences of man such as logging or intensive agricultural efforts. In the three summer seasons there was no evidence of the dams blocking passage of any fish moving upstream in search of cool water.

It is understood that the thermal features of a beaver impoundment may not be the limiting factor on trout production, either in the pond or in the creek below, because fish usually acclimate to withstand extremes of high water temperature. Both in ponds and downstream from them the warmer waters furthermore provide creek chubs and other competing species with an apparent advantage over the brook trout. Rarely a limited thermal rise occasioned by beaver ponds may improve the environment for trout by warming, and such appeared to hold for at least part of Hunt Creek, Montmorency County, Michigan.

IV

## WATER CHEMISTRY

Besides the thermal effects of beaver work on trout streams, there are many aspects of water chemistry which are influenced by the activities of this mammal. Of these, oxygen content alone seems to be affected in a way harmful to trout. Although acidity, free carbon dioxide, and hardness are also changed, their importance to salmonids is either obscure or of little magnitude.

Severe oxygen depletion during the summer months occurred on two beaver-pond series, and two others also exhibited an overall decline progressing downstream. In other seasons the impounded water showed little chemical difference from that of the streams except for slight depression of dissolved oxygen under the ice. For the most part the reduced content found during the summer did not prevail below the dams; water passing over the structures and downstream became aerated.

Analyses of pH, carbon dioxide, and methyl orange alkalinity yielded data to which little of significance in the lives of trout could be attached. Excess acidity resulting from the decomposition of coniferous vegetation did not occur in the ponds under study, nor was it noted during the extensive survey phase of this investigation. Values of carbon dioxide determinations inversely followed those of the oxygen, and provided some evidence of the organic decay. Although the exact relation of methyl orange alkalinity to fish life is not known, tests for this provided an indication of the overall productivity. No analyses were made of methane, other decomposition gases, or nutrient materials, but some biochemical-oxygen-demand tests were run.

A. Methods and Sampling Schedule

In determining the dissolved oxygen content, the unmodified Winkler method was suitable. All the figures for this gas were recorded in parts per million (p.p.m.) but were later converted to percentages of saturation, using Rawson's nomogram (1944). Values obtained were not corrected for either altitude (about 1800 feet above sea level), or barometric pressure.

In some cases the oxygen values reflected the abundance of algae at the sampling stations, and the effects of photosynthetic activity became apparent in a 24-hour series of water analyses run on the large upper Morrison Creek beaver pond. Photosynthesis appeared to be the predominant source of oxygen. Replenishment by absorption from the pond surface probably was very slight for such a locale as a beaver flowage, where the wind sweeps are short. The type of vegetation flooded had some effect on the oxygen loss, but rain usually increased a pond's content of this gas. The latter was not the case for McGinty Creek, which was fed by the most extensive headwater coniferous swamps of any study stream. No attempt was made to determine the role of subterranean water or bottom decomposition in oxygen depletions.

A Hellige glass-disc comparometer was used for pH, measurements. Determinations of carbon dioxide with a Nessler tube and N/44-sodium hydroxide solution presented some difficulty. Gradual deterioiration of the standard with time probably severely affected the values obtained during the summer of 1948. However, in the following two years bottles of a special type glass prevented any losses of strength during the remainder of the study. Only a few water samples from the streams showed any phenolphthalein alkalinity, but that measured by methyl orange indicator was of interest.

In 1948 the interval between analyses had been fortnightly, except for weekly chemical series in the month of August when decomposition was most severe. From mid-June through early September they were made weekly on primary study streams for the last two years of the investigation. Oxygen determinations and pH readings were carried out at every station, and the alkalinity and carbon dioxide figures came largely from the uppermost and downstream locations of a ponded series. Analyses during other seasons were made irregularly. Titrations were performed in the field except for those carried out during the winter or after dark.

Water samples were collected in a special modification of the Hale sampler devised by Greenbank (1943). Lowering to a depth of two to three feet, usually midway between the surface and bottom, provided a value for the oxygen figure somewhere between these two extremes. At times a pair of samples was taken to show these significant differences, but usually only a single one came from any location. In establishing the stations for chemical water analyses, possible maximum and minimum areas of oxygen content were taken into account. The former included the head ends of the ponds and aquatic plant beds; the latter embodied the dams themselves, and localized zones of decomposition. As many as three areas were selected in one pond, upper Morrison Creek, but in a series of small impoundments, such as those on Bluff Creek, only one sample station was established. The differences in chemical characteristics within a short stretch of a large beaver pond will be apparent in the detailed review which follows.

No determinations were made for the amounts of such decomposition gases as ammonia, methane, and hydrogen sulfide. In beaver ponds the threat of the first of these products of decay to fish life is not as serious as those of the other two, and the odor test for the last is the most sensitive. However, these features are worthy of further investigation in any continuation of the present effort. The import of available nutrients in stream water was likewise not taken into account during this study.

B. <u>Summary of Chemical Characteristics of Study Streams</u>

(1) Middle Branch of the Ontonagon River

Over three years of field work seven stations provided water samples towards the headwaters of the Middle Branch west of Watersmeet. From time to time oxygen analyses were made in and below the rapid stretch by the Wolf Lake Road bridge (Figure 2) to learn the content before the stream reached the impoundment. An important site throughout the investigation was located about a third the distance up the pond from its dam (Station A). Samples here were from the edge of the flowing channel alongside a flooded meadow association where the substrate was decaying.

The face of the holding structure was the lowermost sampling site (Station C) in the main pond during 1948. Later it was shifted to the site of the maximum-minimum thermometer mounted in the flowage 20 yards upstream (Station B). This was again on the line between the old stream bed and the marginal vegetation, which was under almost two feet of water when the dam was best maintained. The outlet of this home pond was neglected in 1948, but it was analyzed for oxygen in 1949 and 1950. The samples came from below the main dam (Station D), except for a brief period in 1949 when the animals built an auxiliary one some distance downstream; then the water was taken from the overflow of this lowermost structure.

In 1948, eight analyses at the two stations in the main pond showed a critical amount of oxygen on only one occasion, and then not much below the 5 p.p.m.-limit set for brook trout waters (Table 11). The upper station had a range of 3.9 p.p.m. and 38 percent saturation, and at the dam (Station C) the corresponding figures were 2.7 p.p.m. and 21 percent. Between these two sites there was a consistent decline in the oxygen content of the water.

At times during 1948 the water was light brown in the flooded marsh vegetation but colorless in the stream proper. Aroma of decaying vegetation was strong twice at Station A, and once inshore from the south end of the dam itself. These odors were noted in mid-August, which was often the hottest part of the summer. Similar observations came in 1949 on one occasion in each of three months (May, June, and July) at the former location. No beds of floating or submerged higher aquatic vegetation developed in this pond, although mats of algae appeared sporadically near the dam in late summer.

Oxygen conditions were more serious for trout here during 1949 than at any other time, although they were satisfactory during this year on each of the four checks upstream at the Wolf Lake Road bridge. Within the impoundment the situation was quite different: eight analyses at each site revealed critical values more than half the time. At Station A, five of the results indicated water not favorable for brook

Table 11. Summer Ranges of Dissolved Oxygen, Middle Branch of the Ontonagon River.

| Season and Station | MINIMUM VALUES Date and time | Temperature(°F.) Air | Temperature(°F.) Water | p.p.m. | % Sat. | Means: p.p.m., % sat. | MAXIMUM VALUES Date and time | Temperature(°F.) Air. | Temperature(°F.) Water | p.p.m. | % Sat. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1948, July 12 through Sept. 4: | | | | | | | | | | | |
| Wolf L. Rd. | | .. | .. | .. | .. | ... | July 12, 10:30a.m. | 72 | 67 | 7.4 | 79 |
| Sta. A | Aug. 27, 3:00p.m. | 76 | 70 | 4.3 | 47 | 6.7 - 68 | Aug. 6, 1:15p.m. | 70 | 56 | 8.2 | 78 |
| (Eight analyses, one unfavorable for trout*) | | | | | | | Aug. 14, 3:30p.m. | 78 | 63 | 8.2 | 85 |
| Sta. C | Aug. 27, 4:00p.m. | 76 | 70 | 4.2 | 46 | 5.9 - 59 | Aug. 14, 4:20p.m. | 73 | 59 | 6.9 | 67 |
| (Eight analyses, one unfavorable for trout) | | | | | | | | | | | |
| 1949, June 17 through Sept. 1: | | | | | | | | | | | |
| Wolf L. Road | Aug.18, 10:15 a.m. | 66 | 66 | 5.7 | 60 | 6.8 - 71 | Sept. 1, 3:30p.m. | 60 | 55 | 8.4 | 79 |
| | | | | | | | (Four analyses, none unfavorable for trout) | | | | |
| Sta. A | Aug. 18, 1:15p.m. | 73 | 67 | 3.5 | 37 | 5.0 - 53 | Sept. 1, 3:50p.m. | 62 | 55 | 7.2 | 67 |
| (Eight analyses, five unfavorable for trout) | | | | | | | | | | | |
| Sta. B | Aug. 18, 1:40p.m. | 73 | 69 | 3.1 | 34 | 4.3 - 45 | Sept. 1, 4:45p.m. | 59 | 55 | 6.2 | 57 |
| (Eight analyses, seven unfavorable for trout) | | | | | | | | | | | |
| Sta. D | Aug. 9, 3:45p.m. | 86 | 76 | 5.2 | 61 | 5.7 - 63 | July 1, 4:10p.m. | 80 | 74 | 5.8 | 66 |
| (Three analyses, none unfavorable for trout) | | | | | | | Aug. 2, 3:10p.m. | 65 | 64 | 6.1 | 63 |

* Less than 5 p.p.m.

Table 11. Continued. Summer Ranges of Dissolved Oxygen, Middle Branch of the Ontonagon River.

| Season and Station | MINIMUM VALUES Date and time | Temperature (°F.) Air | Water | p.p.m. | % Sat. | Means: p.p.m., % sat. | MAXIMUM VALUES Date and time | Temperature (°F.) Air | Water | p.p.m. | % Sat. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1949, July 12 through Sept. 4, continued: | | | | | | | | | | | |
| New Dam | Aug. 18, 11:50a.m. | 68 | 68 | 4.0 | 44 | ... | .... .... | .. | .. | ... | .. |
| Outlet | Aug. 18, 2:20p.m. | 74 | 69 | 4.5 | 49 | 5.7 - 58 | Sept. 1, 5:00p.m. | 59 | 56 | 7.2 | 68 |
| (Three analyses, one unfavorable for trout) | | | | | | | | | | | |
| 1950, June 12 through Sept. 7: | | | | | | | | | | | |
| Wolf | Aug. 3, 11:30a.m. | 60 | 56 | 7.8 | 73 | | | | | | |
| L. Rd. | Aug. 11, 10:15a.m. | 58 | 57 | 7.6 | 73 | 7.7 - 75 | July 21, 9:20a.m. | 65 | 60 | 8.1 | 80 |
| | July 11, 10:45a.m. | 76 | 65 | 7.3 | 75 | | (Six analyses, all favorable for trout) | | | | |
| Pond head | Aug. 3, 11:10a.m. | 60 | 55 | 8.0 | 74 | 8.2 - 78 | Aug. 11, 10:15a.m. | 56 | 58 | 8.5 | 82 |
| | | | | | | | (Two analyses, each favorable for trout) | | | | |
| Sta. A | June 12, 3:40p.m. | 78 | 66 | 7.4 | 78 | 8.2 - 85 | July 21, 11:00a.m. | 71 | 64 | 8.8 | 91 |
| (Seven analyses, all favorable for trout) | | | | | | | | | | | |
| Sta. B | June 12, 2:40p.m. | 78 | 66 | 7.6 | 80 | 8.2 - 84 | Aug. 25, 2:15p.m. | 60 | 62 | 8.7 | 88 |
| (Seven analyses, all favorable for trout) | | | | | | | | | | | |
| Sta. D | Aug. 3, 1:30p.m. | 62 | 59 | 7.8 | 76 | 8.2 - 82 | Aug. 11, 11:15a.m. | 60 | 59 | 8.5 | 83 |
| (Four analyses, all favorable for trout) | | | | | | | Aug. 25, 2:10p.m. | 61 | 61 | 8.5 | 86 |