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The Influence of Temperature and Discharge on
Movement Patterns of Brook Trout, Salvelinus Fontinalis,
in the Ford River, Dickinson County, Michigan

presented by

Steven M. Marod

has been accepted towards fulfillment
of the requirements for

Master of Science degree in Fisheries & Wildlife

William W. Taylor
Major professor

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# THE INFLUENCE OF TEMPERATURE AND DISCHARGE ON MOVEMENT PATTERNS OF BROOK TROUT, *SALVELINUS FONTINALIS*, IN THE FORD RIVER, DICKINSON COUNTY, MICHIGAN

BY

Steven M. Marod

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Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

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1995

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## ABSTRACT

## THE INFLUENCE OF TEMPERATURE AND DISCHARGE ON MOVEMENT PATTERNS OF BROOK TROUT, *SALVLEINUS FONTINALIS*, IN THE FORD RIVER, DICKINSON COUNTY, MICHIGAN

By

Steven M. Marod

The influence of late spring and summer water temperatures and discharge on brook trout movement was evaluated from 1984 to 1991 in the Ford River, Michigan. Brook trout were sampled from late May through September using fyke nets and weirs at four locations within 25.8 km of stream. Brook trout were tagged at two sites and their movement monitored through two sites upstream. Spring and summer water temperature, discharge, population abundance, age structure, and beaver dams affected movement. Brook trout greater than 200 mm vacated the Ford River when mean daily water temperatures approached 20°C and entered Two Mile Creek, a cold water tributary. Brook trout movement began and peaked earlier with rapid warming in spring. Sustained temperatures above 20°C shortened movement period duration. Brook trout catch was higher during high discharge events. Trout managers must consider the mobile behavior of this brook trout population when setting management goals.

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# INTRODUCTION

Brook trout are an important sport fish in Michigan inland waters. Stream brook trout in northern Michigan obtain maximum lengths of 500 mm, however, fish of this size are rare. Most brook trout are less than 3 years of age (McFadden 1961, Brasch et al. 1973, McCrimmon 1960, Wydoski and Cooper 1966, Cooper 1967, and Bridges 1958) as they experience high natural mortality or exploitation. These fish are relatively slow growing with most females maturing by age 2 and some males as early as age 1 (McFadden 1961, Dutil 1976, Cooper 1967). In thermally marginal streams trout densities are low due to low survival and growth can be fast (Treml 1992); especially where food is not a limiting factor.

Growth of brook trout is highly dependent on water temperature with young-of-the-year and yearling brook trout sustaining maximum growth between 12.4 and 15.4° C. (McCormick et al. 1972). Above these temperatures growth slows and mortality increases. Optimum growth temperature for adults was 16° C. (Hokanson et al. 1973) with the upper lethal temperature being 25.3° C. (Fry et al. 1946).

In order to optimize their growth, survival and reproduction, populations of stream dwelling fish often

exhibit mobility. In studying migration patterns of the fish community in a North Carolina stream, Hall (1975) suggested that fish migration and reproduction were coupled to optimize the use of energy resources. Heape (1931) defined movement patterns in three basic categories: 1. alimental, or migrations to more abundant food areas, 2. climatic, where fish seek refuge from unfavorable environmental conditions, and 3. gametic, or spawning migrations.

Annual movement patterns of brook trout in Lawrence Creek, Wisconsin were composed of a downstream dispersal of young-of-the-year, an upstream movement of adults for spawning, and a postspawn downstream movement of adults to wintering areas (Hunt 1975). These movements were of a small scale nature as the different habitat components were closely juxtaposed.

A study on Long Pond Outlet in the northern Adirondack Mountains (Flick and Webster 1975) of New York revealed an upstream directed movement of brook trout in spring. Movements of at least 6.6 km (between site distance) were observed. These movements were attributed to competition with abundant non-trout species such as white sucker (Catostomus commersoni), common shiner (Notropis cornutus), creek chub (Semotilus atromaculatus), pearl dace (Semotilus margarita), cutlips minnow (Exoglossum maxillingua), and longnose dace (Rhinichthys cataractae).

Shetter (1968) observed movement tendencies of tagged wild brook trout caught by anglers on the Au Sable River and Hunt Creek in northern lower Michigan. Few fish moved more than 1.6 km from their tagging site. Shetter suggested that this limited movement was probably typical of "good" trout streams in Michigan where temperatures remain ideal during warm weather periods.

In designing an environmental impact study to observe effects of the U. S. Navy's ELF Communications System on fish populations, researchers from Michigan State University's Department of Fisheries and Wildlife noted high spring movement of brook trout in the Ford River in the central Upper Peninsula of Michigan. Results obtained from net and weir operation and angler recapture of marked fish indicated that brook trout movement was directed upstream toward Two Mile Creek, a cold-water tributary (Whelan and Taylor 1984). Mean daily summer temperatures in the mainstream of the Ford River typically remained above the range where positive growth can be sustained (5 - 20° C., Power 1980). Additionally, there appeared to be an association of brook trout movement with discharge events in the Ford River (Marod and Taylor 1990).

This research was undertaken to examine the movement patterns of brook trout in the upper Ford River watershed and further analyze the roles that temperature and discharge play in directing their movement.

## STUDY AREA

The Ford River is a fourth order stream with its headwaters in northern Dickinson and southern Marquette Counties, Michigan. Its source is in the northwest corner of the county near Sagola. Two Mile Creek is a major tributary flowing from southern Marquette County into the Ford River from the north. The Ford River empties into northern Green Bay south of Escanaba, Michigan. The study area flows through forested lands with occasional open meadow and urban areas. Uplands were dominated by sugar maple, white birch, quaking and bigtooth aspen, and white and red pine while lowlands were primarily white cedar, black and white spruce and balsam fir. Much of the study area riparian zone was lined with tag alder.

Four study sites were established on the upper Ford River watershed to monitor trout movement (Figure 1). Sites 1, 2, and 3 were on the Ford River mainstream while Site 4 was located on a cold water tributary, Two Mile Creek. Site 3 was approximately 1.62 river km upstream of Ralph, Michigan. This portion of the river was characterized by sand and silt substrate in low gradient areas and sand, pebble and gravel substrate in riffle areas. Site 2 was approximately 14.7 river km upstream of Site 3. This area

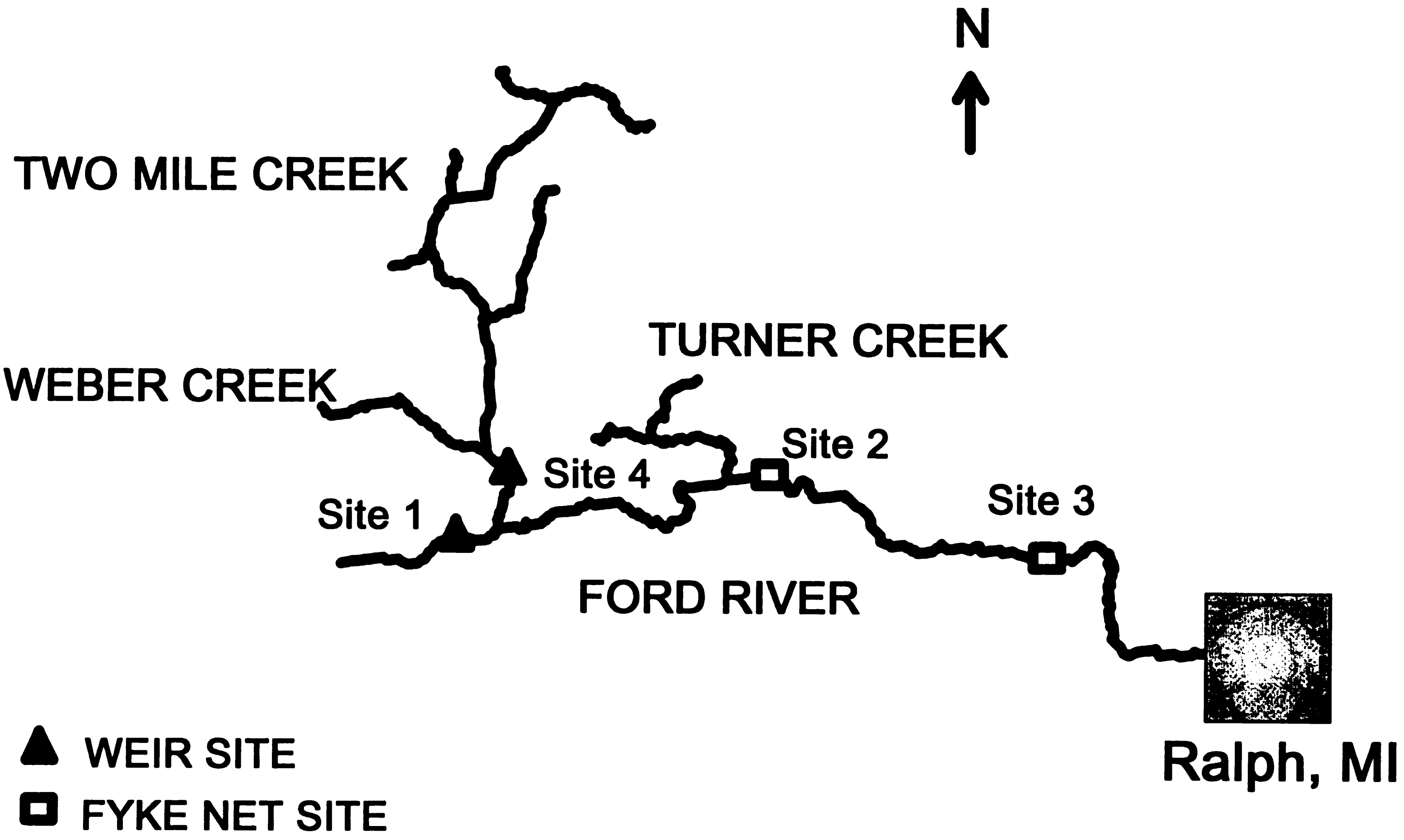


Figure 1. Map of Ford River study sites.

was typified by woody debris on a pebble, gravel substrate with occasional small boulders. Site 1 was approximately 11.1 river km upstream of Site 2 and substrate in this area were predominately of pebbles and cobble. Beaver dams existed upstream of this study area. The other upstream site (Site 4) was located on Two Mile Creek approximately 11.5 river km upstream of Site 2. Downstream of the study site Two Mile Creek was characterized by pebble, gravel, rubble and boulder substrate with abundant woody debris. Upstream of the site the creek meanders through a grassy meadow with tag alder along the stream corridor, and was typified by deep pools with short stretches of riffle. Beaver dams existed and woody debris was abundant in this section of the stream.

# METHODS

## Brook Trout Movement

Brook trout movement in the Ford River was evaluated using fyke nets and weirs at four sites (Figure 1) throughout the upper watershed to recapture tagged trout and by using radiotelemetry techniques.

## Fyke Nets and Weirs

Fyke nets of 1/2 inch bar mesh were implemented at Sites 2 and 3 on the Ford River mainstream. Nets were fished in tandem, one facing upstream and the other downstream so that movement in both directions was observed. Leads stretched across the entire stream section and were supported by 1 inch hexagonal stock rerod for maximum strength. The bottom of each lead was held down by rocks.

Due to lower discharge and more stable substrate at Sites 1 and 4, weirs were constructed of 1/2 inch mesh hardware cloth in a configuration similar to Hall's (1975). The walls of the weirs were supported by 1 inch hexagonal stock rerod and were angled to each stream bank to direct fish toward the traps. The bottom of the walls were held in place with rocks.

In 1984 gear was fished for 44 days at Site 1, 78 days at Site 2, 86 days at Site 3 and 121 days at Site 4 between May 15 and September 22. From 1985 through 1989 all gear was fished 5 days/week. In 1990 and 1991, all gear was fished 7 days/week until the mean daily catch of brook trout fell below 1 fish/day after which all gear was fished from Monday through Friday only. All gear was checked for fish once every 24 hours during all years.

Brook trout captured were anesthetized with MS-222 at a 50 mg/l of water dosage as recommended by Meister and Ritzi (1958) and Schoettger and Julin (1967) to reduce handling stress. Fish were then measured for total length to the nearest 1 mm and weighed on a calibrated Ohaus Port-O-Gram scale to the nearest 0.1 gram. Fish were then scale sampled and each given a site specific fin clip according to the following scheme:

Site 1 - left pectoral
Site 2 - right pelvic
Site 3 - left pelvic
Site 4 - right pectoral

Movements of trout were observed through recapture at other sites and by angler recapture.

In addition to fin clipping, brook trout were tagged using various methods throughout the study. In 1984 and 1985 brook trout were marked using disk or streamer tags. Strap tags applied to the adipose fin or opercle were used in 1986 and 1987. In 1988 brook trout were given a site specific fin clip while from 1989 through 1991 trout greater than 140 mm were tagged with a V. I. (Visible Implant) Tag manufactured by Northwest Marine Technologies.

After recovery in fresh water all fish were released in the direction of travel. Recaptured fish were anesthetized with MS-222, measured, weighed, allowed to recover in fresh water and released. Tag number, initial tagging site and recapture site were noted.

## Radiotelemetry

In 1990 and 1991, 25 upstream migrating brook trout greater than 200 mm captured at Sites 2 and 3 were implanted with radiotelemetry transmitters manufactured by L and L Electronics of Mohomet, Illinois. Each transmitter was equipped with a 30 day battery and an internal loop antenna. Transmitter frequencies ranged from 49 MHz to 50 MHz and were separated by 10 KHz. Each transmitter unit was approximately 2.7 cm long, 1 cm wide and high, and weighed 2.8 to 3.0 grams. The receiver was a scanning type manufactured by Advanced Telemetry Systems (ATS) of Isanti, Minnesota and covered a 2 MHz range (48 - 50 MHz).

Anesthetic and surgical techniques defined by Summerfelt and Smith (1990) were used on fish to be implanted with transmitters. After placement with transmitters, fish were followed entirely by foot as logjams and beaver dams made navigation by canoe difficult. Several fish could be tracked at a time due to the scanning capability of the receiver. When a fish was located it was pinpointed by a unique landmark and then plotted on a United States Geological Survey map. One observation per fish was attempted on an every other day basis with fish tagged at Site 2 being followed one day and those tagged at Site 3 the next day.

Ambient Monitoring

Late spring and summer water temperatures were monitored (half hour intervals) with Omnidata data pods using thermistors at Sites 2 and 3 from mid-April to October (Burton 1991). At Sites 1 and 4 in 1988, Ryan Thermographs were deployed to monitor temperature at 30 minute intervals from late June to mid-September. In 1990 and 1991 Ryan Tempmentors were used to collect temperature data at 30 minute intervals. Tempmentors were deployed from early May to mid-August in 1990 and from late June to mid-September in 1991. In addition, Wecksler max-min thermometers calibrated daily with a laboratory thermometer were used to monitor maximum and minimum temperature at Sites 2, 3, and 4 for all net days in all years.

Mean daily discharge measurements were available for 1986 through 1991. Flow data from a Pygmy Gurley flow meter was combined with gage height readings to establish a stage/flow relationship so that daily discharge could be determined. Mean weekly discharge values were calculated from daily means at Sites 2 and 3.

## Statistical Analysis

All statistical analysis was done using Statistix Analytical Software, version 4.0.

Spearman Rank Correlation was used to associate various movement parameters with different cumulative stream temperature strata. Movement parameters used were: Days from May 1 to the first trout catch, days from May 1 to the peak of the trout movement, and movement duration. The peak of the trout movement was determined to be the date of the highest catch or the mean date if several consecutive high catches were recorded. Movement duration was from the first recorded catch to when catches fell to 1 trout or less per day. Cumulative stream temperature strata used were: Number of days mean daily water temperatures exceeded 16°C and 20°C during May, June, July, May through June, and May through July. I selected 16°C and 20°C since they define brook trout upper limits for optimum growth (Raleigh 1982) and positive growth (Fry et. al. 1946) respectively.

Associations of flow patterns between Sites 2 and 3 were determined using Pearson Correlation analysis. Two sample t-tests ($p < 0.05$) were used to determine the effects of discharge on trout catch. Unequal variances were assumed. I tested the discharge when trout catch was one or more versus discharge when trout catch was zero. These tests

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tests were done over the entire study season and for the movement period May 1 through July 31.

Pearson Correlation was used to define relationships between brook trout movement rates (km/day to move from one site to a site further upstream) and mean temperature, mean discharge, and the number of days from May 1 to the tagging date. The latter correlation defined whether fish tagged early or late during the movement period moved at different rates.

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# RESULTS

## Fish Collection

Efforts in total fyke net days at all sites varied substantially from year to year (Table 1) due largely to variable start times and the duration of high stream flow patterns. Net days at Site 2 ranged from a high in 1984 (78) to lows in 1985 and 1986 (42). Effort at Site 3 ranged from 86 net days in 1984 to 52 net days in 1986. Weir days at Site 1 ranged from 69 in 1990 and 1991 to 39 in 1987 while Site 4 weir operation days ranged from 121 in 1984 to 38 in 1987.

Brook trout catch was highly variable between sites and between years (Table 2). Annual catch varied from 288 trout in 1989 to 1186 trout in 1984. Mean annual catch was 537.6 trout. The annual catch was highest at Site 4 on Two Mile Creek in all years except 1987 when Site 2 had the highest catch. This is probably due to the fact that Site 4 was characterized by water temperatures during the hottest periods in the summer that were 3-5°C cooler than the other sites.

Brook trout catches at Sites 2 and 3 peaked in late May to early July depending on weather patterns during the year

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Table 1. Total net days at all Sites from 1984 through 1991.

| Year | Site 1 | Site 2 | Site 3 | Site 4 |
|---|---|---|---|---|
| 1984 | 44 | 78 | 86 | 121 |
| 1985 | 53 | 42 | 58 | 61 |
| 1986 | 52 | 42 | 52 | 51 |
| 1987 | 39 | 57 | 59 | 38 |
| 1988 | 56 | 55 | 53 | 54 |
| 1989 | 52 | 69 | 70 | 71 |
| 1990 | 69 | 69 | 68 | 69 |
| 1991 | 69 | 60 | 55 | 72 |

Table

| Site |
|---|
| 1 |
| 2 |
| 3 |
| 4 |

Table 2. Total annual catch at Sites 1, 2, 3, and 4 from 1984 to 1991.

| | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Site | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| 1 | 180 | 56 | 33 | 16 | 28 | 0 | 102 | 74 |
| 2 | 170 | 79 | 69 | 291 | 43 | 47 | 59 | 99 |
| 3 | 313 | 138 | 82 | 140 | 66 | 78 | 33 | 119 |
| 4 | 523 | 273 | 120 | 150 | 178 | 163 | 127 | 452 |

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(Appendix I). Summer catches then dropped to < 1 fish per day and this condition persisted through late August to early September. In years (1987-1989) gear was fished into October trout catch increased in September and October with movements toward spawning areas in the upper portion of the Ford River study area and Two Mile Creek.

The upstream component of the catch throughout each study season was higher than the downstream component at all sites in all years (Table 3). The total number of trout caught moving upstream in all years at all sites was 3694 while 607 were captured moving downstream. The upstream component of the catch averaged 65.6 % at Site 1, 84.4 % at Site 2, 89.7 % at Site 3, and 90.1 % at Site 4 over all years.

Mean lengths of brook trout captured at Sites 2 and 3 (Table 4) varied between years. Mean length of brook trout captured at Site 3 were significantly larger than those caught at Site 2 (2 sample t-test, $p<0.05$). Brook trout mean lengths at Site 2 ranged from 172.3 mm (s.d.=79.6) in 1988 to 236.2 mm (s.d.=66.4) in 1985. Mean lengths recorded at Site 3 ranged from 205.0 mm (s.d.=78.0) in 1988 to 245.8 mm (s.d.=48.7) in 1989.

## Tagging

Numbers of fish tagged at Sites 2 and 3 varied between years depending on catch (Table 5). Numbers of fish marked

Table

| Site |
|---|
| 1 |
| 2 |
| 3 |
| 4 |

Table 3. Total catch moving upstream and downstream at Sites 1, 2, 3, and 4 from 1984 to 1991.

| | | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Site | Dir | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| 1 | Up | 100 | 42 | 26 | 12 | 16 | | 65 | 40 |
| | Down | 80 | 14 | 7 | 4 | 12 | | 37 | 34 |
| 2 | Up | 477 | 269 | 112 | 137 | 150 | 133 | 106 | 441 |
| | Down | 46 | 4 | 8 | 13 | 28 | 30 | 21 | 11 |
| 3 | Up | 115 | 66 | 43 | 227 | 39 | 47 | 56 | 97 |
| | Down | 55 | 13 | 26 | 64 | 4 | 0 | 3 | 2 |
| 4 | Up | 285 | 122 | 71 | 137 | 57 | 60 | 31 | 115 |
| | Down | 28 | 16 | 11 | 3 | 9 | 18 | 2 | 4 |

Table 4. Mean length (std. dev.) of brook trout caught at Sites 2 and 3 from 1984 through 1991.

| Year | Site 2 | Site 3 |
|---|---|---|
| 1984 | 191.1 (64.7) | 231.5 (53.8) |
| 1985 | 236.2 (66.4) | 229.5 (54.2) |
| 1986 | 175.3 (44.2) | 217.4 (53.1) |
| 1987 | 190.3 (50.1) | 212.3 (40.8) |
| 1988 | 172.3 (79.6) | 205.0 (78.0) |
| 1989 | 228.9 (61.2) | 245.8 (48.7) |
| 1990 | 205.6 (75.7) | 230.3 (65.0) |
| 1991 | 213.0 (66.2) | 232.9 (44.1) |

Table 5. Brook trout marking summary at Sites 2 and 3 from 1984 through 1991.

| Year | Mark | Site 2 | Site 3 |
|---|---|---|---|
| 1984 | Floy Tagged | 71 | 243 |
| | Fin Clipped | 48 | 37 |
| 1985 | Floy/Disk Tagged | 45 | 81 |
| | Fin Clipped | 38 | 53 |
| 1986 | Strap Tagged | 15 | 40 |
| | Freeze Branded | 19 | 8 |
| | Fin Clipped | 58 | 32 |
| 1987 | Strap Tagged | 97 | 73 |
| | Fin Clipped | 127 | 41 |
| 1988 | Fin Clipped | 57 | 85 |
| 1989 | V. I. Tagged | 49 | 86 |
| | Fin Clipped | 12 | 11 |
| 1990 | V. I. Tagged | 46 | 28 |
| | Fin Clipped | 12 | 5 |
| 1991 | V. I. Tagged | 78 | 109 |
| | Fin Clipped | 36 | 21 |

at Site 2 ranged from 57 in 1988 to 224 in 1987. At Site 3, numbers of tagged fish ranged from 33 in 1990 to 280 in 1984.

The number of tagged brook trout recaptured was variable over the course of the study (Table 6). In 1984 18.2% (57) of tagged fish were recaptured. This dropped to 12.7% (26) in 1985 and 0.0% in 1986 through 1988. Brook trout recapture percentage then increased to 6.7% (7) in 1989, 9.7% (2) in 1990 and 34.2% (74) in 1991.

## Movement

In 1984, 1985, and 1991 site to site recapture patterns were similar (Table 7). In 1984, 39 of 57 (68.4%) recaptures were from Site 3 to Site 4. In 1985 and 1991 movement from Site 3 to Site 4 was 37.5% (9 of 26) and 44.6% (33 of 74) respectively. Movement from Site 2 to Site 4 made up 19.3% of total recaptures in 1984, 37.5% in 1985 and 31.1% in 1991. Movement from Site 3 to Site 2 was observed for 12.5% of total recaptures in 1984, 15.4% in 1985 and 8.1% in 1991. The fact that Site 2 is between Sites 3 and 4 demonstrates that significant escapement occurred at Site 2. Escapement may have occurred due to high water undermining fyke net wings, removal of gear during high water or on weekends, or muskrat or beaver damage.

Little downstream movement of tagged brook trout occurred over the course of the study. One fish in both

Table 6. Brook trout recapture summary for Sites 2 and 3 combined from 1984 through 1991.

| Year | % Tag Recapture |
|---|---|
| 1984 | 18.2% |
| 1985 | 12.7% |
| 1986 | 0.0% |
| 1987 | 0.1% |
| 1988 | 0.0% |
| 1989 | 6.7% |
| 1990 | 9.7% |
| 1991 | 34.2% |

Table 7. Brook trout site to site recapture and movement rate summary for 1984 through 1991.

| Year | Site Marked to Site Recaptured | Distance (km) | N | Mean Rate (km/day + 1SD) |
|---|---|---|---|---|
| 1984 | Site 2 - Site 4 | 12.7 | 11 | 1.4 ± 0.9 |
| | Site 3 - Site 4 | 26.8 | 39 | 2.9 ± 1.7 |
| | Site 3 - Site 2 | 14.1 | 7 | 2.7 ± 1.6 |
| 1985 | Site 2 - Site 4 | 12.7 | 7 | 1.6 ± 0.9 |
| | Site 3 - Site 4 | 26.8 | 6 | 5.0 ± 3.2 |
| | Site 3 - Site 2 | 14.1 | 3 | 1.2 ± 0.3 |
| 1986 | | | | |
| 1987 | Site 2 - Site 4 | 12.7 | 1 | 1.8 |
| 1988 | Site 3 - Site 2 | 14.1 | 2 | 2.3 ± 0.7 |
| 1989 | Site 2 - Site 4 | 12.7 | 2 | 0.7 |
| | Site 3 - Site 4 | 26.8 | 1 | 4.5 |
| | Site 3 - Site 2 | 14.1 | 1 | 2.8 |
| | Site 2 - Site 3 | 14.1 | 2 | 1.9 |
| | Site 4 - Site 3 | 26.8 | 1 | 6.7 |
| 1990 | Site 3 - Site 2 | 14.1 | 2 | 2.2 |
| 1991 | Site 3 - Site 2 | 14.1 | 9 | 2.3 |
| | Site 2 - Site 4 | 12.7 | 23 | 1.6 |
| | Site 3 - Site 4 | 26.8 | 33 | 3.5 |
| | Site 1 - Site 4 | 3.0 | 9 | 0.7 |
| | Site 2 - Site 3 | 14.1 | 1 | 3.5 |
| | Site 4 - Site 3 | 26.8 | 1 | 1.0 |
| | Site 4 - Site 2 | 12.7 | 1 | 12.7 |

1989 and 1991 moved from Site 4 in Two Mile Creek to Site 3 on the Ford River near Ralph, Michigan. Also in 1991 a tagged trout from Site 4 was recaptured at Site 2. Movement from Site 2 to Site 3 occurred for one fish in 1985, two in 1989, and 1 in 1991. Two fish in 1985 and 9 in 1991 were observed moving downstream from Site 1 and then ascending Two Mile Creek to Site 4.

Movement from Sites 2 and 3 to Site 4 was undertaken mainly by trout greater than 200 mm. Brook trout recaptured at Site 4 were significantly larger than trout tagged at Sites 2 and 3 (2 sample t-test, $p<0.05$) in 1991.

Temperature

Mean daily temperatures during the run (May 1 through July 31) at Sites 2 and 3 were variable from year to year (Table 8). The average temperature for this time period at Site 2 for all years was 16.81°C and ranged from 15.16°C in 1985 to 19.17°C in 1988 (Table 8).

Spearman Rank Correlation suggested that total annual brook trout catch was not strongly associated with mean temperature from May 1 to July 31 ($r=-0.0183$) for 1984 through 1991. Total annual brook trout catch was not associated with mean temperatures at Site 3 from May through July 31 (Pearson Correlation, $r=-0.0838$) for 1984 through 1991. Annual brook trout catch at Site 3, however, was negatively associated with mean temperatures at Site 2

Table 8. Mean temperature (standard deviation) from May 1 through July 31 at Sites 2 and 3 from 1984 to 1991.

| Year | Site | Mean |
|---|---|---|
| 1984 | Site 2 | 15.24 (4.13) |
| | Site 3 | 15.88 (4.28) |
| 1985 | Site 2 | 15.16 (3.13) |
| | Site 3 | 15.38 (3.11) |
| 1986 | Site 2 | 16.99 (3.48) |
| | Site 3 | 17.14 (3.30) |
| 1987 | Site 2 | 17.66 (4.02) |
| | Site 3 | 17.33 (3.96) |
| 1988 | Site 2 | 19.17 (4.23) |
| | Site 3 | 18.23 (4.09) |
| 1989 | Site 2 | 17.99 (4.74) |
| | Site 3 | 15.65 (4.50) |
| 1990 | Site 2 | 15.33 (4.52) |
| | Site 3 | 14.85 (4.43) |
| 1991 | Site 2 | 16.91 (4.25) |
| | Site 3 | 16.97 (4.31) |

(Pearson Correlation, r=-0.4178). This suggests that higher temperatures upstream corresponded to reduced catches at Site 3.

Temperature patterns from May 1 through July 31 at Sites 2 and 3 changed somewhat over the course of the study (Appendix II). Significant differences in mean temperatures were seen between Sites 2 and 3 in 1984, 1985 and 1988 through 1990 (paired t-test, $p<0.05$). No differences were seen in 1986, 1987 and 1991 (Table 9).

Thermal recorders provided mean daily temperature information at Sites 1 and 4 in 1988, 1990 and 1991 (Appendix III). One way analysis of variance of mean daily temperatures at all sites during these years detected significant differences between the means. Tukey's pairwise comparison of means test ($P < 0.05$) identified three different temperature patterns in 1988 (Table 10). Site 2 was significantly warmer than Sites 1, 3 and 4. Mean temperatures at Sites 1 and 3 were similar while Site 4 was significantly cooler than all other sites. In 1990 (Table 11) and 1991 (Table 12), no differences in mean temperatures at Sites 1, 2 and 3 were identified. Site 4 was significantly cooler than all other sites.

## Relationship between Catch and Mean Daily Temperature

Spearman Rank Correlations were used to test the relationship between catch and temperature. Different

Table 9. Results of paired t-test between mean daily temperatures from May 1 through July 31 at Sites 2 and 3 in all years.

| Year | P value | Significant |
|---|---|---|
| 1984 | 0.0000 | Y |
| 1985 | 0.0000 | Y |
| 1986 | 0.1995 | N |
| 1987 | 0.0525 | N |
| 1988 | 0.0000 | Y |
| 1989 | 0.0000 | Y |
| 1990 | 0.0000 | Y |
| 1991 | 0.1105 | N |

Table 10. Results of Tukey's HSD multiple range test on mean daily temperature during summer at all sites on the Ford River in 1988.

| Site | Mean | Homogeneous Groups | | |
|---|---|---|---|---|
| Site 2 | 22.60 | I | | |
| Site 3 | 21.30 | | I | |
| Site 1 | 20.48 | | I | |
| Site 4 | 17.73 | | | I |

Table 11. Results of Tukey's HSD multiple range test on mean daily temperature during summer at all sites on the Ford River in 1990.

| Site | Mean | Homogeneous Groups | |
|---|---|---|---|
| Site 2 | 18.77 | I | |
| Site 3 | 18.30 | I | |
| Site 1 | 18.05 | I | |
| Site 4 | 16.85 | | I |

Table 12. Results of Tukey's HSD multiple range test on mean daily temperature during summer at all sites on the Ford River in 1991.

| Site | Mean | Homogeneous Groups | |
|---|---|---|---|
| Site 3 | 19.15 | I | |
| Site 2 | 18.79 | I | |
| Site 1 | 18.28 | I | |
| Site 4 | 17.22 | | I |

characteristics of movement; days to the first recorded catch, days to the peak catch, and duration of movement (Tables 13 and 14); were correlated with various temperature strata (Tables 15 and 16). Spearman Rank Correlation suggested a strong negative relationship (r=-0.762) at Site 2 between days to the first recorded catch and number of days mean daily temperatures exceeded 16°C in June (Table 17). The number of days to the peak of the movement was negatively associated with days mean daily water temperatures exceeded 20°C in May (r=-0.507) (Table 17). Strong negative associations existed between movement duration and days mean temperature exceeded 20°C in May (-0.756) and May through July (r=-0.6112) (Table 17). Positive relationships existed between movement duration and days temperature surpassed 16°C in June (r=0.2304) and May through June (r=0.1320) (Table 17).

Spearman Rank Correlations also defined associations between movement and temperature at Site 3 (Table 18). The number of days to the first recorded catch at Site 3 was negatively correlated to the number of days mean temperature exceeded 16°C in June (r=-0.595), May through June (r=-0.714), and May through July (r=-0.643). The number of days from May 1 to the peak catch also showed a strong negative association with the number of days over 16°C in May (r=-0.727), June (r=-0.701), May through June (r=-0.952), and May through July (r=-0.952). The number of days from May 1

Table 13. Days from May 1 to the first brook trout catch, days to the peak catch and duration of movement period at Site 2 on the Ford River from 1984 through 1991.

| | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| First Catch | 15 | 48 | 22 | 41 | 19 | 23 | 31 | 17 |
| Peak Catch | 39 | 54 | 80 | 47 | 45 | 59 | 67 | 59 |
| Duration | 72 | 37 | 70 | 30 | 28 | 38 | 49 | 75 |

Table 14. Days from May 1 to the first brook trout catch, days to the peak catch and duration of movement period at Site 3 on the Ford River from 1984 through 1991.

| | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| First Catch | 15 | 22 | 21 | 40 | 19 | 23 | 31 | 17 |
| Peak Catch | 35 | 65 | 35 | 48 | 33 | 65 | 54 | 25 |
| Duration | 72 | 31 | 65 | 30 | 33 | 37 | 41 | 75 |

Table 15. Days temperature exceeded 16° C and 20° C during May, June, July, May-June and May-July at Site 2 in the Ford River study area from 1984 through 1991.

| Parameter | Year 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|
| >16° May | 0 | 0 | 6 | 6 | 9 | 13 | 0 | 13 |
| >16° June | 26 | 7 | 20 | 22 | 30 | 23 | 17 | 29 |
| >16° July | 28 | 31 | 31 | 31 | 31 | 31 | 30 | 28 |
| >16° May-June | 26 | 7 | 26 | 28 | 39 | 36 | 17 | 42 |
| >16° May-July | 54 | 38 | 57 | 59 | 70 | 67 | 47 | 70 |
| >20° May | 0 | 0 | 0 | 3 | 3 | 0 | 0 | 0 |
| >20° June | 1 | 0 | 1 | 13 | 15 | 11 | 4 | 7 |
| >20° July | 1 | 3 | 18 | 18 | 28 | 29 | 12 | 9 |
| >20° May-June | 1 | 0 | 1 | 16 | 18 | 11 | 4 | 7 |
| >20° May-July | 2 | 3 | 19 | 34 | 46 | 40 | 16 | 16 |

Table 16. Days temperature exceeded 16° C and 20° C during May, June, July, May-June and May-July at Site 3 in the Ford River study area from 1984 through 1991.

| | Year | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Parameter | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
| >16° May | 0 | 0 | 6 | 3 | 6 | 2 | 0 | 13 |
| >16° June | 28 | 10 | 21 | 22 | 29 | 12 | 13 | 30 |
| >16° July | 29 | 31 | 31 | 31 | 31 | 31 | 30 | 30 |
| >16° May-June | 28 | 10 | 27 | 25 | 35 | 14 | 13 | 43 |
| >16° May-July | 57 | 41 | 58 | 56 | 66 | 45 | 43 | 73 |
| >20° May | 0 | 0 | 0 | 0 | 2 | 0 | 0 | 0 |
| >20° June | 3 | 0 | 2 | 13 | 12 | 0 | 2 | 7 |
| >20° July | 4 | 5 | 19 | 14 | 22 | 16 | 7 | 9 |
| >20° May-June | 3 | 0 | 2 | 13 | 14 | 0 | 2 | 7 |
| >20° May-July | 7 | 5 | 21 | 27 | 36 | 16 | 9 | 16 |

Table 17. Spearman Rank Correlation coefficients from associations between days to first recorded catch, days to the peak catch, and duration of movement period with days temperature exceeded 16° C and 20° C in May, June, July, May-June and May-July at Site 2.

| Temperature Parameter | First Catch | Peak Catch | Duration of Movement |
|---|---|---|---|
| >16° May | -0.297 | 0.149 | 0.000 |
| >16° June | -0.762 | -0.479 | 0.071 |
| >16° May-June | -0.539 | -0.157 | 0.036 |
| >16° May-July | -0.491 | -0.115 | -0.060 |
| >20° May | 0.126 | -0.507 | -0.756 |
| >20° June | -0.108 | -0.241 | -0.491 |
| >20° May-June | -0.108 | -0.241 | -0.491 |
| >20° May-July | 0.095 | 0.078 | -0.611 |

Table 18. Spearman Rank Correlation coefficients from associations between days to first recorded catch, days to the peak catch, and duration of movement period with days temperature exceeded 16° C and 20° C in May, June, July, May-June and May-July at Site 3.

| Temperature Parameter | First Catch | Peak Catch | Duration of Movement |
|---|---|---|---|
| >16° May | -0.258 | -0.727 | 0.233 |
| >16° June | -0.595 | -0.701 | -0.060 |
| >16° May-June | -0.714 | -0.952 | 0.547 |
| >16° May-July | -0.643 | -0.952 | 0.524 |
| >20° May | -0.247 | -0.417 | -0.247 |
| >20° June | -0.120 | -0.701 | -0.060 |
| >20° May-June | -0.241 | -0.774 | -0.012 |
| >20° May-July | 0.347 | -0.467 | -0.240 |

to the peak catch was also associated with the number of days over 20°C in June and May through June (Table 18). The duration of movement showed positive relationships with the number of days temperatures surpassed 16°C in May through June ($r=0.547$) and May through July ($r=0.524$).

## Discharge

Flow patterns during the entire study season (May 1 through September 6) between 1984 and 1991 were variable (Figures 2 and 3). Generally, flows were high in spring and lower in summer with occasional increased discharge events during summer. Mean weekly discharge values at Sites 2 and 3 from 1986 through 1991 were highly correlated in all years (Pearson's correlation; minimum $r=0.946$, maximum $r=0.997$) therefore only Site 2 data are shown (Figures 2 and 3).

## Relationship between Catch and Mean Daily Discharge

Associating brook trout movement with discharge was difficult as the majority of the brook trout movement occurred during spring when high flows were the norm. Mean discharge when catch was 1 trout or more (Site 2=0.882 $m^3/s$, s.d.=.602; Site 3=1.088 $m^3/s$, s.d.=0.599) was significantly greater than mean discharge when catch was 0 (Site 2=0.685 $m^3/s$, s.d.=.466; Site 3=0.711 $m^3/s$, s.d.=0.517) for all years combined (study period May 18-September 6) at Sites 2 and 3 (2 sample t-test, $p<0.05$) (Table 19). Mean discharge

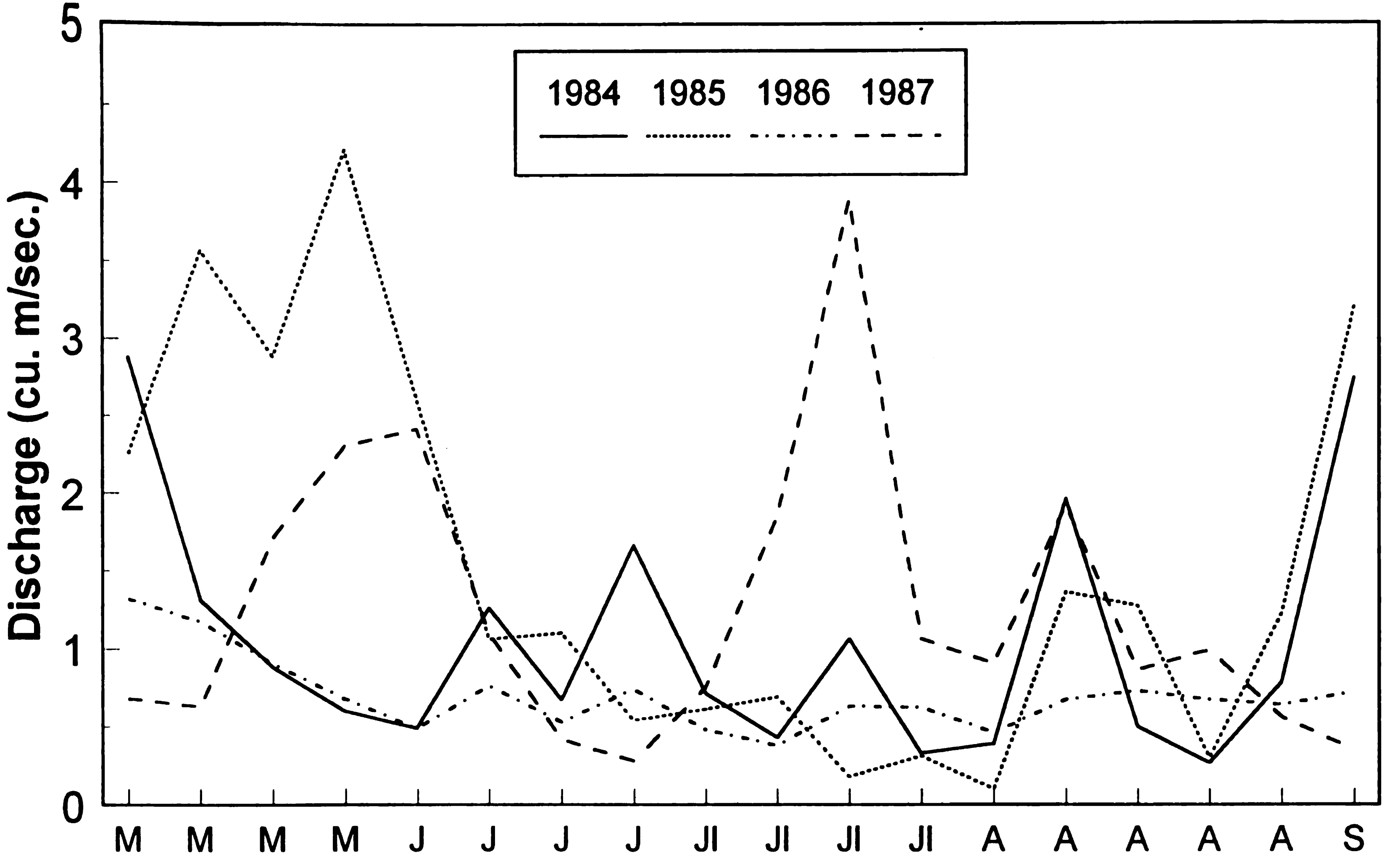


Figure 2. Mean daily discharge calculated on a weekly basis at Site 2 on the Ford River from 1984 through 1987.

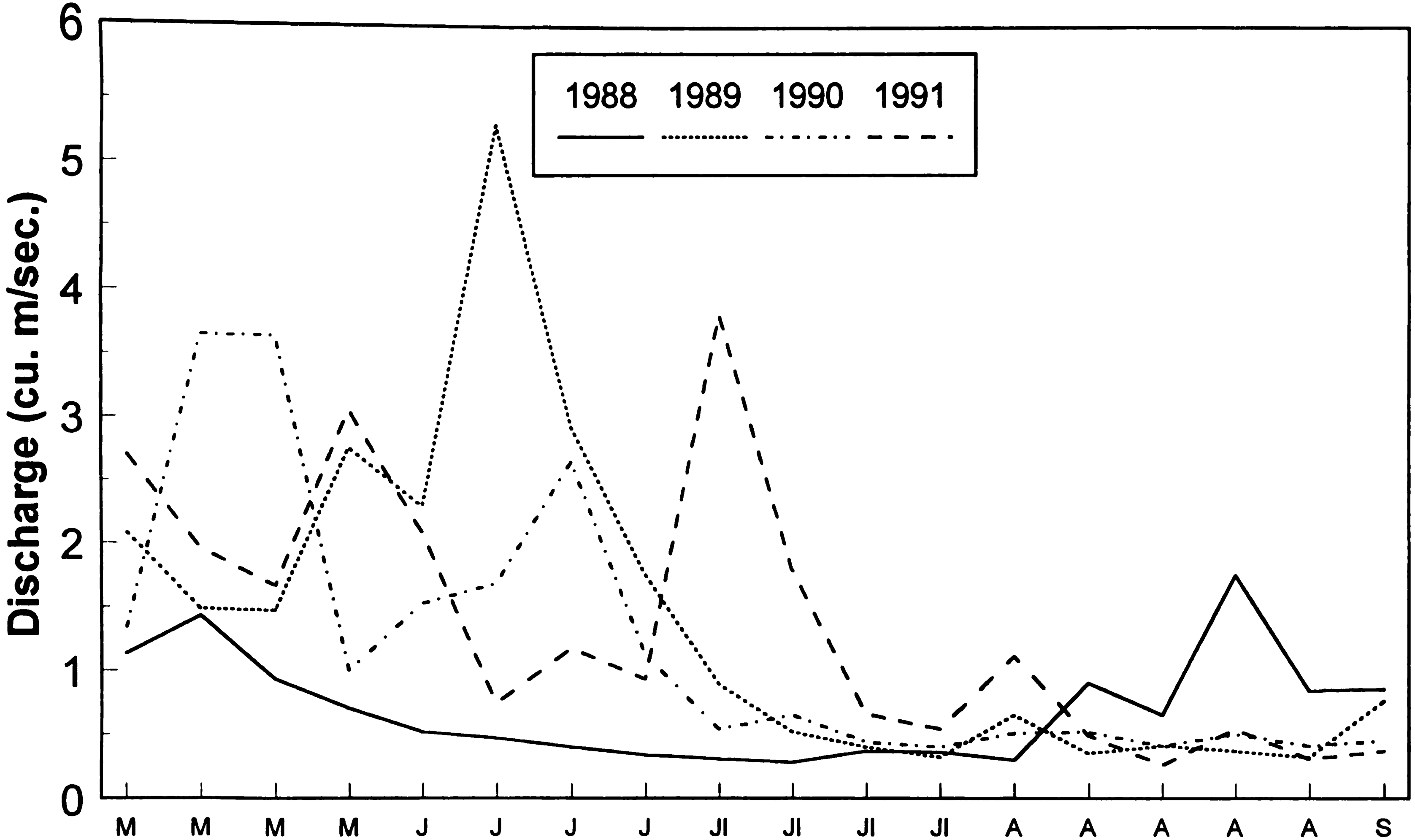


Figure 3. Mean daily discharge calculated on a weekly basis at Site 2 on the Ford River from 1988 through 1991.

Table 19. Results of two sample t-test ($p<0.05$) comparing discharge (cms) when the brook trout catch was 1 or more versus discharge when the catch was 0 at Sites 2 and 3 for all years combined on the Ford River.

| Site | Mean Q Catch≥1 | Mean Q Catch=0 | p Value | Significant |
|---|---|---|---|---|
| 2 | 0.882 | 0.685 | 0.0007 | Y |
| 3 | 1.088 | 0.711 | 0.0000 | Y |

when trout catch was 1 or more was greater than when catch was 0 in all years except at Site 2 in 1986. These tests were not always significant, however (2 sample t-test, $p<0.05$) (Tables 20 and 21).

Confining analysis to the period of the brook trout run (May 1 through July 31) did not significantly alter results. Mean discharge when catch was 1 trout or more (Site 2=0.897 $m^3/s$, s.d.=.605; Site 3=1.098 $m^3/s$, s.d.=0.631) was still significantly greater than mean discharge when catch was 0 (Site 2=0.717 $m^3/s$, s.d.=.520; Site 3=0.740 $m^3/s$, s.d.=0.574) for all years combined at Sites 2 and 3 (2 sample t-test, $p<0.05$) (Table 22). When examining all years individually at Sites 2 and 3, mean discharge was greater when trout were caught except at Site 2 in 1986 and 1990. Results of these tests were not always significant (2 sample t-test, $p<0.05$) (Tables 23 and 24).

## Movement Rates

A distinct trend was observed for movement rates of fish traveling from Sites 2 and 3 to Site 4. Brook trout tagged at Site 3 consistently had faster movement rates to Site 4 than fish tagged at Site 2 (Table 25). Mean annual movement rates from Site 3 to Site 4 ranged from 2.9 km/day in 1984 to 5.0 km/day in 1985. From Site 2 to Site 4, mean annual movement rates ranged from 0.67 km/day in 1989 to 1.6 km/day in 1985 and 1991.

Table 20. Results of two sample t-test ($p<0.05$) comparing discharge (cms) when the brook trout catch was 1 or more versus discharge when the catch was 0 over the entire year at Site 2 on the Ford River from 1986 through 1991.

| Year | Mean Q Catch≥1 | Mean Q Catch=0 | p Value | Significant |
|---|---|---|---|---|
| 1986 | 0.578 | 0.714 | 0.1062 | no |
| 1987 | 0.777 | 0.633 | 0.2386 | no |
| 1988 | 0.876 | 0.666 | 0.2803 | no |
| 1989 | 0.897 | 0.543 | 0.0033 | yes |
| 1990 | 0.970 | 0.829 | 0.4274 | no |
| 1991 | 1.114 | 0.739 | 0.0159 | yes |

Table 21. Results of two sample t-test ($p<0.05$) comparing discharge (cms) when the brook trout catch was 1 or more versus discharge when the catch was 0 over the entire year at Site 3 on the Ford River from 1986 through 1991.

| Year | Mean Q Catch≥1 | Mean Q Catch=0 | p Value | Significant |
|---|---|---|---|---|
| 1986 | 0.912 | 0.690 | 0.0030 | yes |
| 1987 | 1.031 | 0.833 | 0.1503 | no |
| 1988 | 0.744 | 0.642 | 0.4558 | no |
| 1989 | 1.014 | 0.595 | 0.0003 | yes |
| 1990 | 1.275 | 0.870 | 0.0882 | no |
| 1991 | 1.439 | 0.686 | 0.0000 | yes |

Table 22. Results of two sample t-test ($p<0.05$) comparing discharge (cms) when the brook trout catch was 1 or more versus discharge when the catch was 0 at Sites 2 and 3 from May 1 through July 31 for all years combined on the Ford River.

| Site | Mean Q Catch≥1 | Mean Q Catch=0 | p Value | Significant |
|---|---|---|---|---|
| 2 | 0.897 | 0.717 | 0.0154 | Y |
| 3 | 1.098 | 0.740 | 0.0000 | Y |

Table 23. Results of two sample t-test ($p<0.05$) comparing discharge (cms) when the brook trout catch was 1 or more versus discharge when the catch was 0 from May 1 through July 31 at Site 2 on the Ford River from 1986 through 1991.

| Year | Mean Q Catch$\geq$1 | Mean Q Catch=0 | p Value | Significant |
|---|---|---|---|---|
| 1986 | 0.542 | 0.693 | 0.1074 | no |
| 1987 | 0.763 | 0.646 | 0.5483 | no |
| 1988 | 0.468 | 0.354 | 0.0066 | yes |
| 1989 | 0.994 | 0.664 | 0.0323 | yes |
| 1990 | 1.042 | 1.053 | 0.9609 | no |
| 1991 | 1.205 | 1.004 | 0.2978 | no |

Table 24. Results of two sample t-test ($p<0.05$) comparing discharge (cms) when the brook trout catch was 1 or more versus discharge when the catch was 0 from May 1 through July 31 at Site 3 on the Ford River from 1986 through 1991.

| Year | Mean Q Catch$\geq$1 | Mean Q Catch=0 | p Value | Significant |
|---|---|---|---|---|
| 1986 | 0.819 | 0.721 | 0.2045 | no |
| 1987 | 1.075 | 0.667 | 0.0506 | no |
| 1988 | 0.437 | 0.252 | 0.0009 | yes |
| 1989 | 1.132 | 0.761 | 0.0203 | yes |
| 1990 | 1.259 | 1.136 | 0.6442 | no |
| 1991 | 1.442 | 0.923 | 0.0032 | yes |

Table 25. Movement rates of brook trout from Sites 2 and 3 to Site 4 for 1984 through 1991.

| Year | Site Mark | Site Recap | Dist (km) | N | Mean (km/day) |
|---|---|---|---|---|---|
| 1984 | 2 | 4 | 12.7 | 11 | 1.4 |
| | 3 | 4 | 26.8 | 39 | 2.9 |
| 1985 | 2 | 4 | 12.7 | 7 | 1.6 |
| | 3 | 4 | 26.8 | 6 | 5.0 |
| 1986 | No Recaptures | | | | |
| 1987 | 2 | 4 | 12.7 | 1 | 1.8 |
| 1988 | No Recaptures | | | | |
| 1989 | 2 | 4 | 12.7 | 2 | 0.7 |
| | 3 | 4 | 26.8 | 1 | 4.5 |
| 1990 | No Recaptures | | | | |
| 1991 | 2 | 4 | 12.7 | 23 | 1.6 |
| | 3 | 4 | 26.8 | 33 | 3.5 |

Fish tagged later during the movement period travelled at a faster rate than fish tagged earlier in the season. Movement rates from all sites in 1991 were positively correlated with the number of days from May 1 to the tagging date. Correlation coefficients ranged from r = 0.351 for fish moving from Site 3 to Site 4 to r = 0.536 for fish moving from Site 2 to Site 4. No definable relationship was found between mean daily temperature and movement rates.

Movement rates of fish from Site 2 to Site 4 were weakly positively correlated (Pearson's Correlation, r=0.164) to discharge. Rates observed for fish moving from Site 3 to Site 4 and Site 3 to Site 2 were negatively correlated (r=-0.567 and r=-0.484 respectively) to discharge.

Larger fish took more time to move between sites. In 1991 a weak positive correlation was observed between brook trout total length and days it took to move from Sites 2 (r=0.108) and 3 (r=0.268) to Site 4.

## Radio Telemetry

Efforts to follow individual brook trout through radio telemetry provided marginal results. Twenty-five upstream moving trout ranging from 254 mm to 338 mm were radio-tagged in 1990 and 1991. In 1990, eight fish were implanted with radio-transmitters, 4 at Site 2 and 4 at Site 3. Seventeen brook trout were radio-tagged in 1991, 2 at Site 2 and 15 at

Site 3. Tagging site, length, weight and transmitter frequency for implanted fish in 1990 and 1991 were noted (Table 26).

In 1990, brook trout implanted with transmitters were followed between 6 and 13 days. Mortality or premature transmitter failure determined the length of time individual fish could be followed. In 1991, implanted trout were rarely found due to long range initial movements or transmitter failure. Three fish radio-tagged at Sites 2 and 3 were contacted or recaptured at Site 4. Two of these fish provided information for 12 days, the other for 24 days.

Four of 8 fish tagged in 1990 provided movement information. Upstream movement distances between contacts ranged from 0 km to 3.7 km and averaged 1.2 km. Three of the four trout that moved were last received below beaver dams. Brook trout 48.106, tagged at Site 2, moved upstream approximately 3.8 km in 2 days to the base of a large beaver dam. Contacts made from 12 July through 18 July found the fish staging below the dam. The trout was last received on 20 July and had moved approximately 400 m downstream of the dam. Efforts to find the fish on 23 July failed.

Brook trout 48.332, tagged at Site 3, displayed similar behavior. Tagged on 9 July, the fish was followed moving upstream for 6 days and 7.7 km until a large beaver dam stopped its progress. The fish remained below the dam through 18 July. On 21 July the fish was contacted and

Table 26. List of brook trout surgically implanted with radiotelemetry transmitters in 1990 and 1991.

| Year | Site | Date | Length (mm) | Weight (g) | Transmitter Frequency |
|---|---|---|---|---|---|
| 1990 | 2 | 7/ 7 | 293 | 219.9 | 48.106 |
| | 2 | 7/ 9 | 278 | 215.7 | 48.281 |
| | 2 | 7/10 | 313 | 296.1 | 48.257 |
| | 3 | 7/ 9 | 254 | 185.1 | 48.332 |
| | 3 | 7/10 | 280 | 211.8 | 48.031 |
| | 3 | 7/10 | 333 | 435.3 | 48.308 |
| 1991 | 2 | 5/24 | 338 | 376.4 | 48.606 |
| | 2 | 5/26 | 288 | 223.7 | 48.681 |
| | 3 | 5/22 | 301 | 300.6 | 48.531 |
| | 3 | 5/23 | 318 | 377.9 | 48.581 |
| | 3 | 5/23 | 277 | 241.0 | 48.556 |
| | 3 | 5/24 | 274 | 245.3 | 48.655* |
| | 3 | 5/24 | 279 | ----- | 48.681* |
| | 3 | 5/24 | 271 | ----- | 48.708* |
| | 3 | 5/25 | 292 | 259.8 | 48.708 |
| | 3 | 5/26 | 300 | 284.6 | 48.732 |
| | 3 | 6/ 6 | 268 | 229.5 | 48.655 |
| | 3 | 6/ 6 | 247 | 156.8 | 48.780 |
| | 3 | 6/ 7 | 303 | 304.7 | 48.806 |
| | 3 | 6/ 7 | 255 | 179.5 | 48.829 |
| | 3 | 6/ 7 | 255 | 179.3 | 48.757 |
| | 3 | 6/ 9 | 273 | 216.9 | 48.855 |

* Fish died, transmitter reused.

found dead approximately 400 m downstream of the dam. Another trout tagged at Site 3, 48.031, was received and sighted below a small beaver dam approximately 3.8 km upstream of the tagging site. The fish appeared stressed and was not found the next day. The beaver dam was not impassible as 48.332 had negotiated it.

Tracking radiotagged brook trout in 1991 was difficult. Even though implanted fish were monitored at the release site for one-half hour after surgery, contacting the fish later after checking other sites (3 to 5 hours later) was rarely successful. Initial movements may have exceeded distances I could cover in an evening (Approximately 4 km) or delayed transmitter failures occurred.

No contact was made with brook trout radio-tagged at Site 3 during tracking. One fish was recaptured dead at Site 2 and it had expelled the transmitter. Another fish (48.708) was recaptured at site 4 with a failed transmitter. Two other radio-tagged individuals were contacted staging below the weir at Site 4. Brook trout 48.829 was contacted below Site 4 on 15 and 16 June and was captured in the weir on 17 June. The next day the fish was located less than 100 m upstream of the weir and on 19 June moved approximately 400 m upstream to below remnants of an old beaver dam. Final contact occurred on 21 June at the same site.

Brook trout 48.806 was caught in the weir at Site 4 on 18 June and was transported upstream and released. Last contact was made the next day. Efforts to follow the fish up Two Mile Creek and Weber Creek (a tributary to Two Mile Creek) on 21 June failed.

Two fish were radio-tagged at Site 2 on 25 and 26 May in 1991. Brook trout 48.606 was contacted on 26 and 27 May 300 m upstream of the tagging site. The fish was not contacted on 28 May during a 4.0 km search upstream. Brook trout 48.681 was tagged on 26 May and occupied the same area as 48.606 on 27 May. The fish was not found on 28 May. On 16 June the fish was located below the weir at Site 4. The trout was captured in the weir on 18 June and was found dead the next day upstream of the weir.

Although radio telemetry data provided only marginal tracking results, one important observation was made. Three brook trout fitted with transmitters were located below beaver dams where their movements may have been impeded.

# DISCUSSION

## Fish Collection

Tagging methods changed throughout the course of the study. In 1984 and 1985 streamer and disk tags were used. Angler reports of high post release mortality led to the use of strap tags in 1986 and 1987. Strap tags were attached to the adipose fin in 1986 and to the opercle in 1987. Poor retention was observed using both of these techniques. Freeze branding was also attempted in 1986 but proved to be costly due to the remoteness of the study area and the distant availability of dry ice needed to adequately cool the brand. Site specific fin clips were used in 1988, however, this prevented monitoring of individual fish movements.

Visible Implant (V.I.) Tags were used in 1989 through 1991 and provided excellent results. Tag retention calculated from recaptured trout was high (85.5% in 1991) and individuals tagged in previous years were recaptured in 1990 and 1991 with tags still visible. Mortality due to tagging was not measured although the condition of recaptured trout suggested high survival.

Movement

Studies have shown that brook trout populations undertake substantial seasonal movements in response to various environmental stimuli. Shetter (1968) tagged 3320 brook trout in the Au Sable River in northeastern Michigan and found spring, summer and fall (spawning) movements were both low in frequency and short, ranging form 0.1 to 1.1 miles. Seine hauls during winter in summer habitats, however, recaptured few brook trout. Recaptures in seine hauls in April and May were downstream of summer and autumn habitats. Shetter therefore concluded that the bulk of the population moved downstream during winter months, possibly as far as the mainstream of the Au Sable River, a distance of 18 miles.

Little downstream movement occurred in the Ford River Study area during spring, summer and fall sampling. Hunt (1975) noted a downstream dispersal of young-of-the-year brook trout in Lawrence Creek, Wisconsin. This behavior may occur on the Ford River but may not have been observed due to the 1/2 inch mesh size gear used. Hunt also noted a downstream movement of adult brook trout after spawning in winter. This behavior may occur but would not have been observed on the Ford River as gear was not fished during winter months.

A nine year study on Long Pond Outlet (Flick and Webster 1975) in New York described concentrated movements of brook trout during spring and fall. Spring movements were most frequent making up 50% to 70% of the total. Summer activity was low making up less than 10% of total movements. Movements were in the upstream direction and were at least 6.6 km in distance. Flick and Webster (1975) related decreased brook trout movement to reductions in the populations of competitive species (ie. white sucker, common shiner, creek chub, pearl dace, cutlips minnow, and longnose dace).

Water temperature is probably the single most important factor limiting brook trout distribution and production (McCormick et. al. 1972). Brook trout experience optimal growth between 11°C and 16°C (Raleigh 1982) and positive growth at temperatures between 5°C and 20°C (Fry et. al. 1946). Above 20°C it becomes difficult for brook trout to maintain basal metabolism. In viewing spring and summer water temperature patterns, it is evident that the Ford River provides only marginal brook trout habitat. Temperatures generally exceeded the optimum range by mid June; and the range for positive growth was exceeded in all years.

Brook trout in the Ford River responded to suboptimal temperature conditions by exhibiting mobile behavior in spring and early summer. The tendency was for trout to vacate the mainstream of the Ford River and ascend Two Mile Creek, a cold water tributary. These movements were followed closely in 1984, 1985 and 1991 as substantial numbers of trout marked at Sites 2 and 3 were recaptured upstream at Site 4 in Two Mile Creek.

Brook trout catch was primarily dependant on natural fluctuations in the abundance of the population. Treml (1992) noted that age and size structure appeared to be dependant on spring water temperature patterns and that two consecutive cool summers produced high populations of 2 year old brook trout. High catch rates of 2 year old trout in 1987 and 1991 following two cool summer seasons, supports this hypothesis.

The proportion of 2 year old trout in the catch at Sites 2 and 3 was high in 1984, 1985 and 1991 (Treml 1992). Movements to Site 4 were undertaken predominately by adult trout greater than 200 mm in total length. This is probably due to the fact that larger fish are metabolically less efficient at high temperatures (Schofield et. al. in press) than smaller fish. Therefore, it is more critical for larger fish to find thermal refuge.

In 1986 through 1990, recaptures at Site 4 were few and movement patterns were poorly defined. The presence of large beaver dams, one between Sites 2 and 3 and one separating Sites 1 and 4 from Site 2, may have impeded trout movements. Catches at passive capture fyke net and weir sites were low suggesting a possible decline in trout population abundance or trout were effectively blocked from the gear by the dams.

Drought conditions in 1987 and 1988 may have increased mortality and decreased spawning success of adult trout lowering the population abundance (Treml 1992). Treml (1992) also found that age 2 trout were lower in abundance from 1986 through 1990. Since larger trout show a higher tendency to move from Sites 2 and 3 to Site 4, their low abundance from 1986 through 1990 may further explain lower recapture rates in these years.

Temperature was the main controlling factor affecting brook trout movement at Sites 2 and 3 in the Ford River. Brook trout catch rates increased earlier and peaked earlier in years when water temperatures warmed quickly in May and June. Early peaks were noted in 1984 and 1987 through 1989 when temperatures warmed quickly in spring. Spring was cooler in 1985, 1986, 1990 and 1991 resulting in later movement peaks in these years. The duration of the movement period at Sites 2 and 3 decreased when water temperatures warmed quickly to 20°C in spring. As temperatures exceeded the upper limit for positive growth, the duration of the movement was shortened. This is especially evident in 1987 when the majority of the movement occurred during a 5 day period in mid-June. In contrast, temperatures in 1984 rarely exceeded 20°C and catch rates remained high from mid-May through mid-July.

Measuring the effects of discharge on trout movement was difficult. Gear could not be fished effectively at Sites 2 and 3 when discharge exceeded 3 $m^3/s$. Additionally, fyke nets seemed to lose effectiveness at low flows. Trout appeared able to escape when flows were not adequate to tighten leads to the bottom. Muskrats and beaver were more likely to damage nets during low flows allowing trout to escape. Gear appeared to fish most efficiently at moderate flows (approximately 0.5 to 2.0 $m^3/s$) as current would keep leads tightened to the substrate without undermining.

Two large beaver dams one located between Sites 2 and 3 and one located between Sites 2 and 4 may have interfered with trout movement in some years. The date of construction of the beaver dam between Sites 2 and 4 is unknown (one local angler estimated it was built in the mid 1980s) although its affects on water temperature may have been important. Mean temperatures from 1984 through 1987 were not significantly different at Sites 2 and 3 and movement from Sites 2 and 3 to Site 4 in 1984 (50) and 1985 (19) was substantial. In 1988 and 1989, however, temperatures were significantly warmer at Site 2 than at Site 3. This change may have been due to pond warming at the impoundment above Site 2. Movement of trout from Sites 2 and 3 to Site 4 in 1988 and 1989 was low. High spring discharge in the spring of 1991 removed the dam. Water temperatures returned to patterns seen from 1984 through 1987 and movement of trout from Sites 2 and 3 to Site 4 increased to 56.

Mean discharge was higher when brook trout were caught than when the catch was 0. This relationship was evident in all years except 1986 at Site 2 where mean discharge was higher when no trout were caught. This may be due to stable flows at a moderate level during the movement period in 1986.

Comparing mean discharge when catch of trout was 0 to 2 versus mean discharge when catch was 3 or more showed a weaker association, especially at Site 2. At Site 2 in 1986 and 1990, mean discharge was significantly higher at low catch rates (2 sample t-test, $p<0.05$). This is probably explained by low brook trout abundance during these years and the rarity of catches of more than 2 during the run. In addition, flows in 1990 remained high throughout the brook trout run making it difficult to detect pulses in movement related to flow patterns. In 1987 at Site 2, mean discharge was also higher when catch was 0 to 2 although not significantly. This is likely explained by extremely high catches (> 50 trout/day) during low flows prompted by high temperatures in June.

Brook trout did move during low flows. At Site 2 in 1987, the brook trout catch between 16 June and 19 June averaged 55.8 trout per day when mean daily discharge was 0.42 $m^3/s$, well below average (1.23 $m^3/day$) for that time period. A similar event occurred at Site 3 at the same time. Sustained water temperatures near 24°C were present during this time period. This suggests that trout will not wait for a rise in flow to move if temperature conditions become suboptimal.

Increases in flow due to precipitation events were often associated with an increase in the brook trout catch. Trout catches often remained higher for one or two days after an increase in discharge, especially if flows remained higher for a few days after a precipitation occurred.

Radiotelemetry

Following radio-tagged brook trout revealed that beaver dams located between Sites 2 and 3 and Sites 2 and 4 were effective barriers to movement. Treml (1992) found that by age 2 high summer water temperatures had detrimental effects on Ford River brook trout growth and length at age. She hypothesized that by the end of their second growing season, Ford River brook trout had reached a size where the increase in basal metabolism due to high temperatures could not be completely offset by increased feeding activity (Treml 1992). Beaver dams which exclude trout from thermal refuge, then, could have severe physiological impacts including retarded somatic growth and gametic development, or death. In addition, anglers often targeted brook trout below beaver dams. Many tags returned by anglers were caught below beaver dams. This suggests that blocked trout may be more vulnerable to anglers.

# MANAGEMENT IMPLICATIONS

The Ford River is a marginal brook trout stream due to temperatures that annually exceed the range where positive growth can occur. Brook trout are able to inhabit this environment by moving from high temperatures in the mainstream to thermal refuge areas in Two Mile Creek. In order to sustain this population I believe management strategies should focus on preserving genetic integrity and habitat.

Logging is extremely important to the Upper Peninsula economy. Improper logging practices are probably the biggest threat to the brook trout population in the Ford River watershed. It is vital that foresters work closely with fisheries managers to protect riparian corridors along the river and its tributaries. Logging removed riparian cover and increased siltation on Two Mile Creek near its confluence with the Ford River. The area logged was an established electrofishing site used in 1988 through 1990. This area consistently had high young-of-the-year and yearling brook trout populations. Damaging logging practices such as this should not be allowed.

Thermal refuge areas are extremely important, especially to larger brook trout unable to metabolize efficiently in warm water. Preserving these areas in Two Mile Creek and other tributaries is vital to maintaining habitat capable of supporting brook trout. Maintenance of riparian buffer areas along both the Ford River and its tributaries is extremely important. Educating landowners of the importance of healthy riparian buffer areas would also be valuable.

Current brook trout stocking programs should be evaluated. Brook trout stocked in the Ford River during the study behaved differently than natural fish. Stocked trout often congregated at the mouth of fyke nets, behavior similar to what I had observed in hatchery raceways. In addition, hatchery trout did not show movement behavior characteristic of wild trout. Only two hatchery fish moved between sites during the entire study period. Hatchery trout probably survived poorly when summer water temperatures increased due to the lack of movement behavior. Stocked fish may also compete with wild fish for food and vital habitat.

Genetic studies should be initiated to evaluate the potential uniqueness of the brook trout population in the Ford River. If Brook trout in the Ford River represent a unique strain, stocking could contaminate the population. Interbreeding between wild and hatchery trout may suppress adapted behaviors in the population resulting in lower survival.

Beaver dams have the potential to limit brook trout populations in the Ford River. Because of the necessity of trout to move to thermal refuge when temperatures increase in the spring and summer, barriers excluding trout from these areas could have deleterious impacts to the population. Removal of beaver dams allowing trout to move freely could lower mortality and increase reproductive success. If budgetary constraints prohibit dam removal by DNR personnel, a private group of volunteers could be recruited to do the work.

# SUMMARY

The upper Ford River is classified as a blue ribbon trout stream. From a temperature standpoint, however, the Ford River is a marginal brook trout stream. Summer water temperatures exceeded the range (5°C to 20°C) where brook trout can maintain positive growth in all years (1984 - 1991) of the study. In order to inhabit this environment, brook trout have adapted mobile behavior. When temperatures become suboptimal in late spring/early summer, trout vacate the mainstream of the Ford River and move into Two Mile Creek, a major cold water tributary in the watershed. These movements were observed in 1984, 1985, and 1991. Little site to site movement occurred from 1986 through 1990.

Movement patterns were controlled mainly by the rate of water warming in the spring/early summer. In years where water temperatures rose rapidly past 20°C, movements began and peaked early. Additionally, rapid warming during spring caused the duration of the movement period to be shorter. This was especially evident in the drought years of 1987 and 1988.

Stream discharge also had an impact on catch rates of brook trout. Catches in passive gear were higher at higher discharge rates suggesting that trout reacted favorably to rises in flow. Correlations between extremely high flows and trout catch could not be made as gear was not fished in high discharge events. Trout, however, did not wait for optimum flow patterns to begin movements. In 1987, catch rates were very high (< 50/day) during extremely low flow conditions. Water temperatures exceeding 23°C for several days in a row may have been responsible for these high catch rates.

Brook trout moving from the mainstream of the Ford River into Two Mile Creek were predominately adults (age 2+). In years age 2 and older trout were low in abundance, little site to site movement was observed. This was especially evident during drought years when high temperatures may have increased mortality of adult brook trout. In addition, large beaver dams constructed between mainstream sites and Two Mile Creek may have excluded brook trout from reaching thermal refugia, lending to higher mortality rates. Low population abundance observed in 1989 and 1990 support this hypothesis.

Fisheries management in the Ford River should take into consideration the uniqueness of the brook trout population. This population has developed distinct survival strategies to inhabit a marginal environment. Priority should be placed on preserving thermal refuge areas in Two Mile Creek. Stocking strategies should be assessed and necessity determined. Beaver dams excluding trout from thermal refuge areas should be removed.

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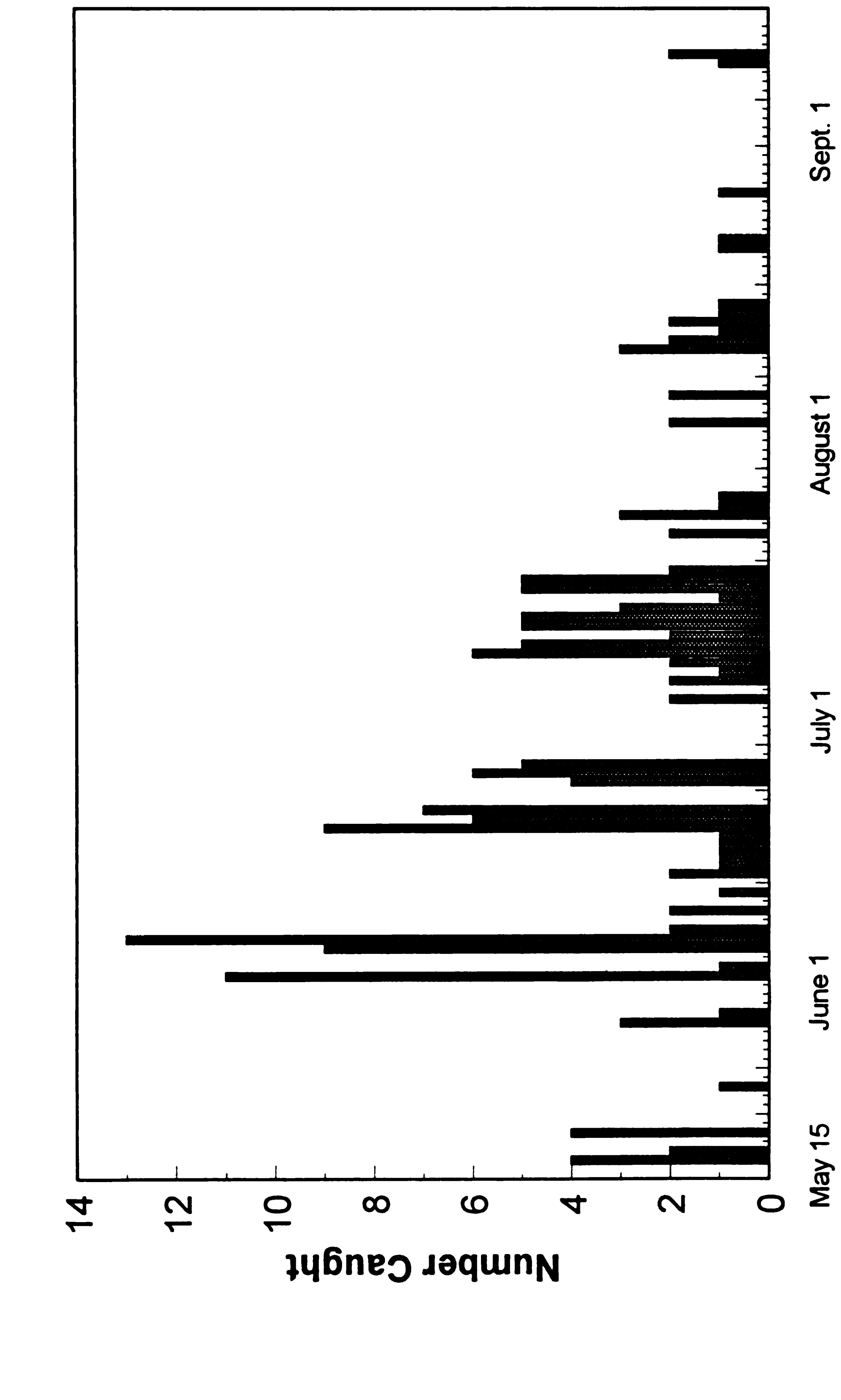
# Appendix I

Appendix I




Figuree 4. Number of brook trout caught each day at Site 2 in 1984.

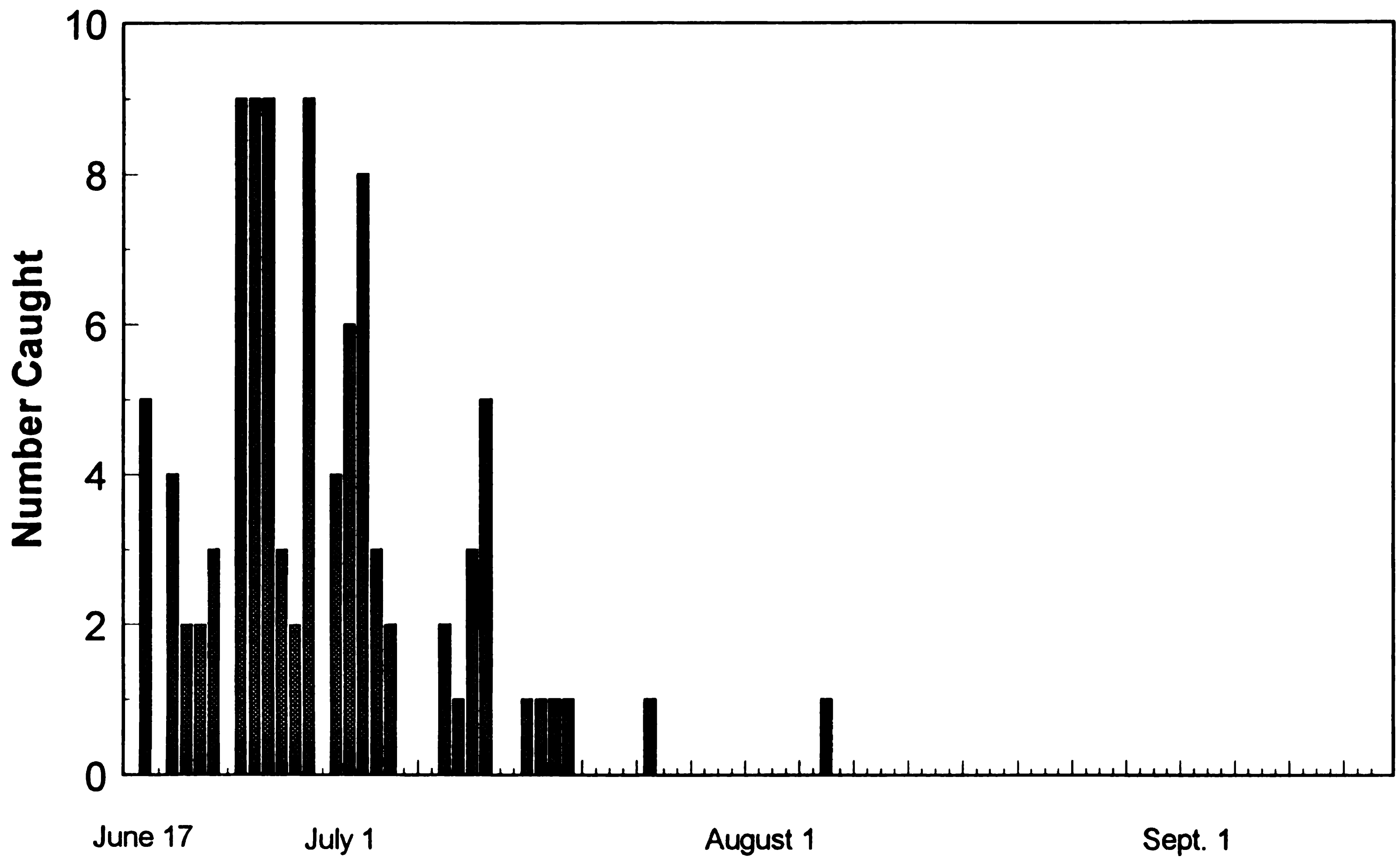



Figure 5. Number of brook trout caught each day at Site 2 in 1985.

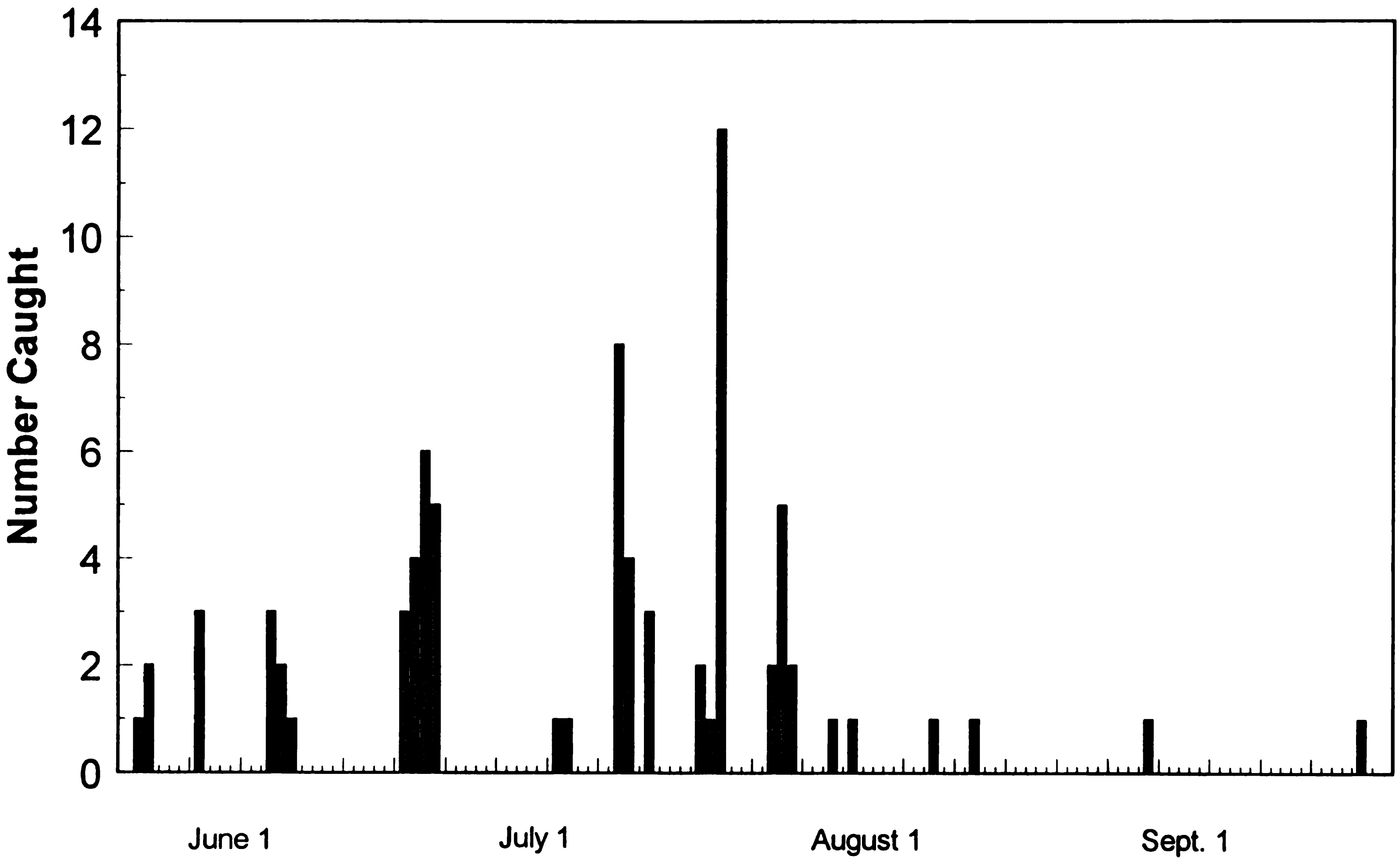



Figure 6. Number of brook trout caught each day at Site 2 in 1986.

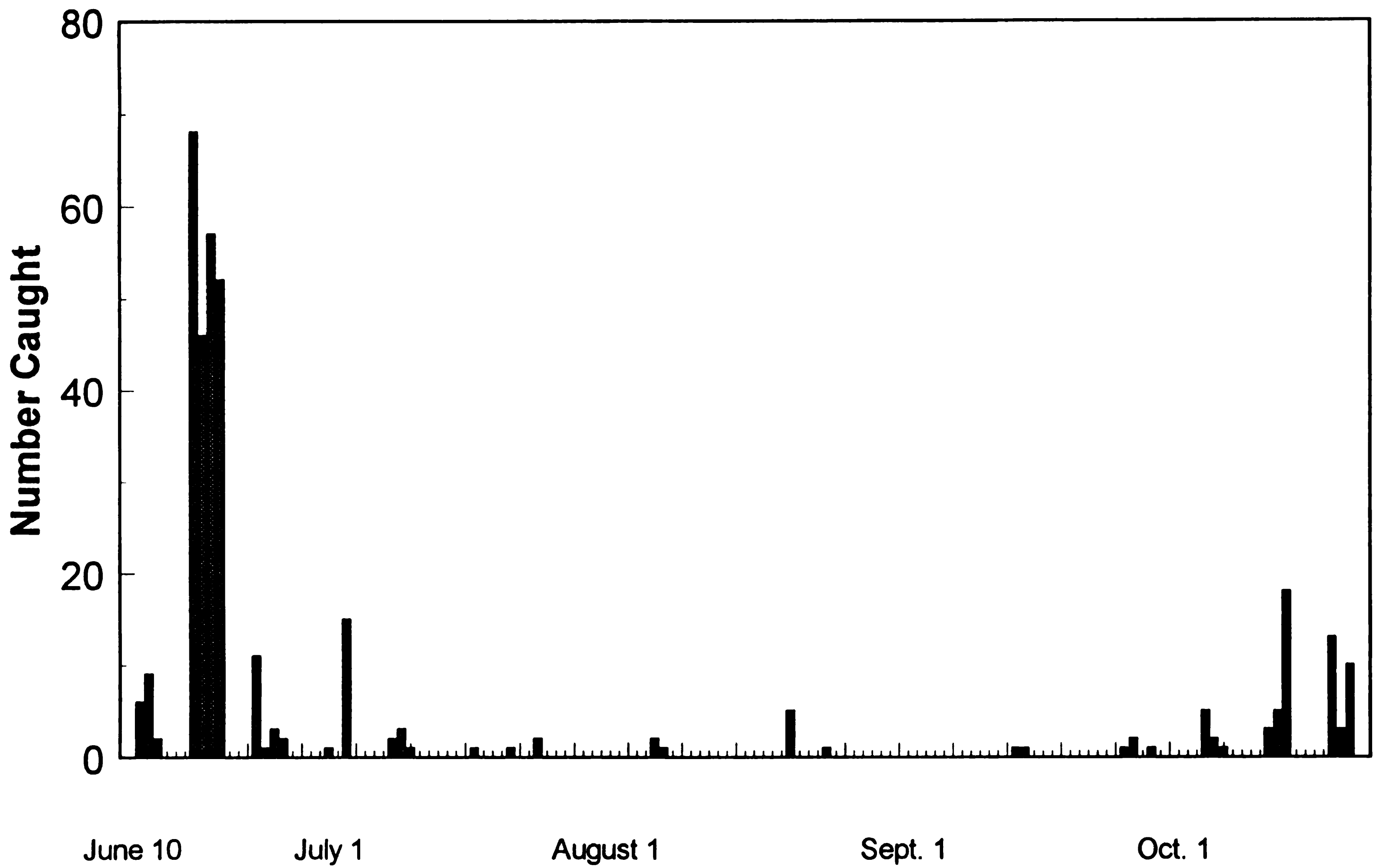



Figure 7. Number of brook trout caught each day at Site 2 in 1987.

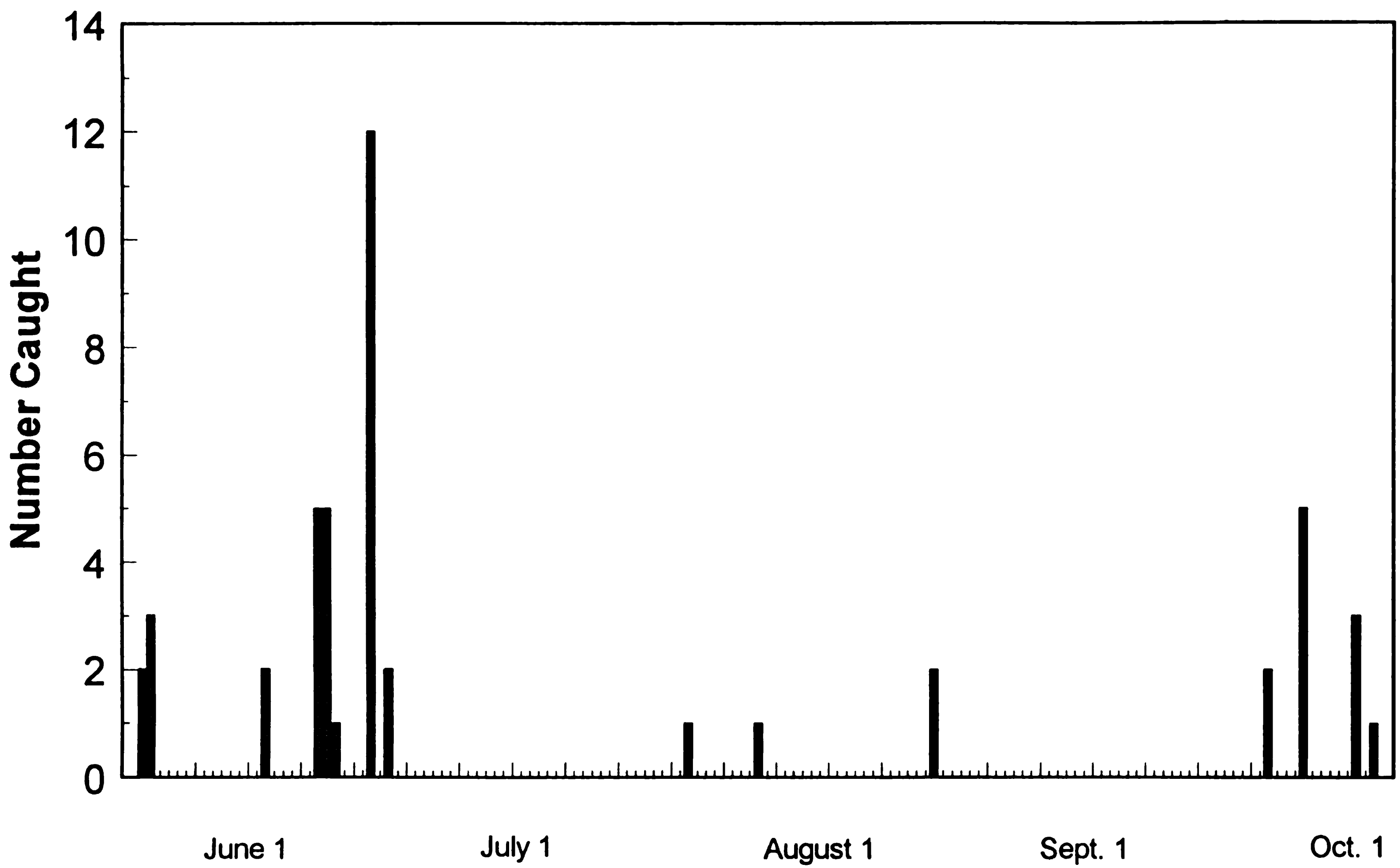



Figure 8. Number of brook trout caught each day at Site 2 in 1988.

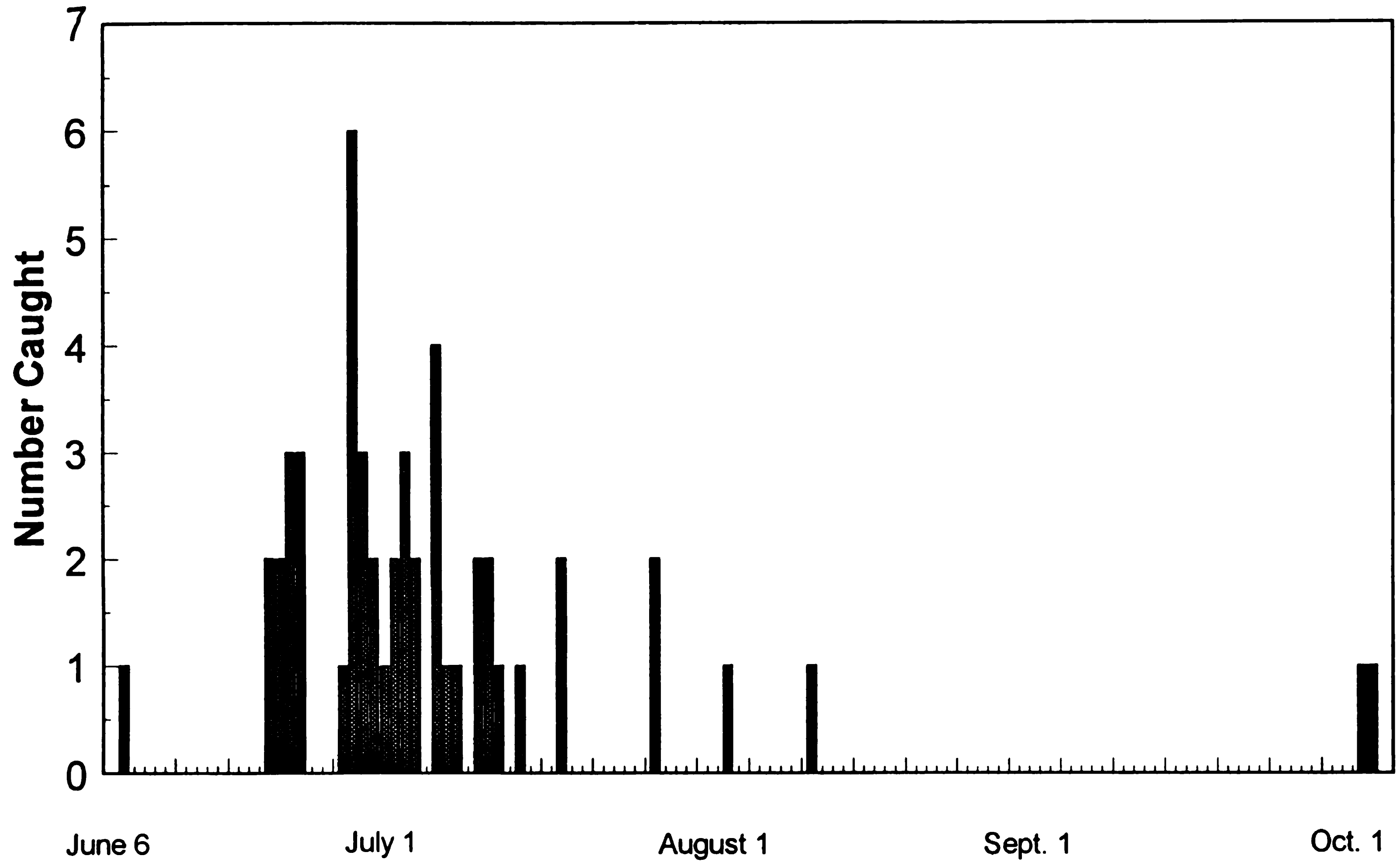



Figure 9. Number of brook trout caught each day at Site 2 in 1989.

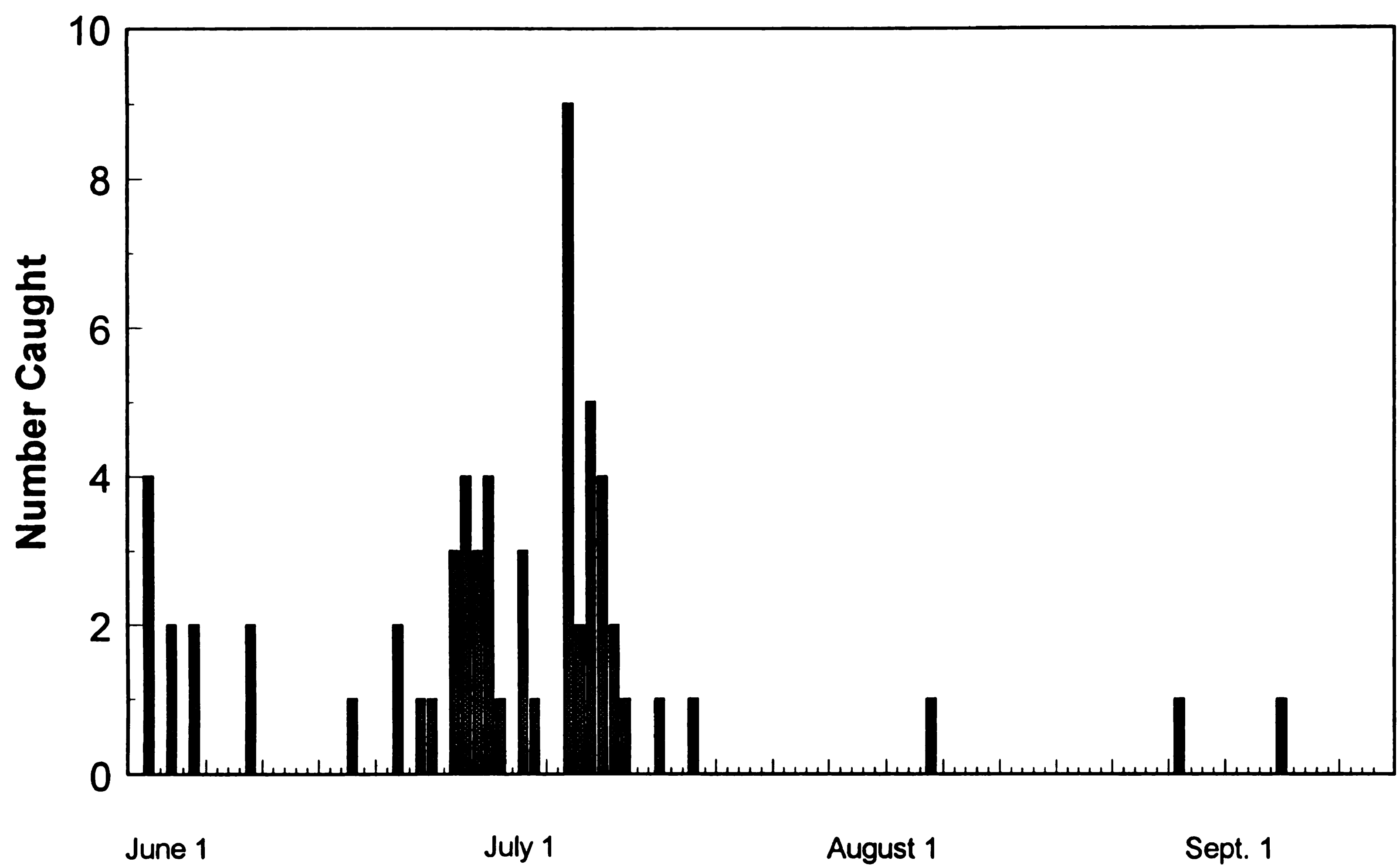



Figure 10. Number of brook trout caught each day at Site 2 in 1990.

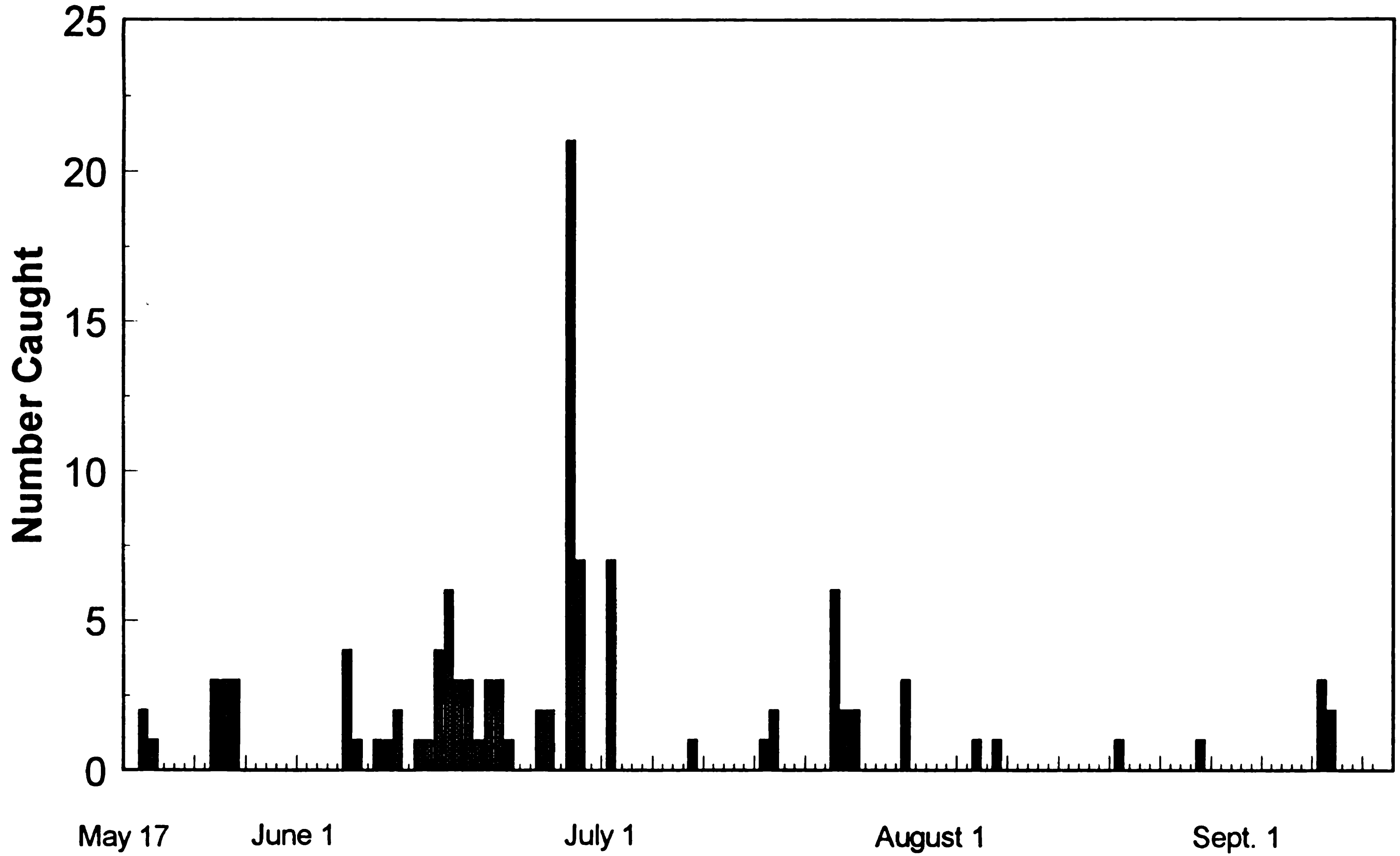



Figure 11. Number of brook trout caught each day at Site 2 in 1991.

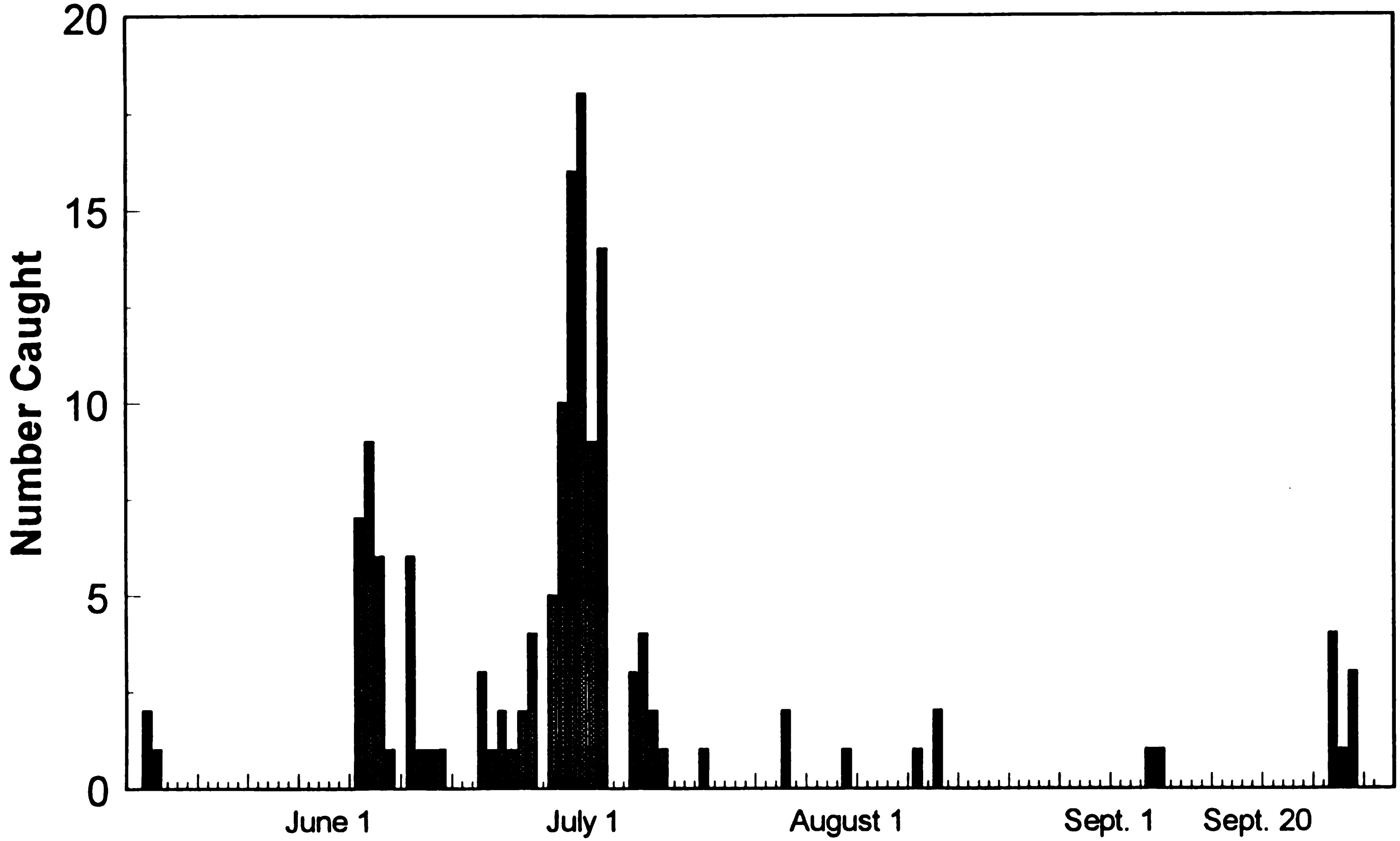



Figure 12. Number of brook trout caught each day at Site 3 in 1985.

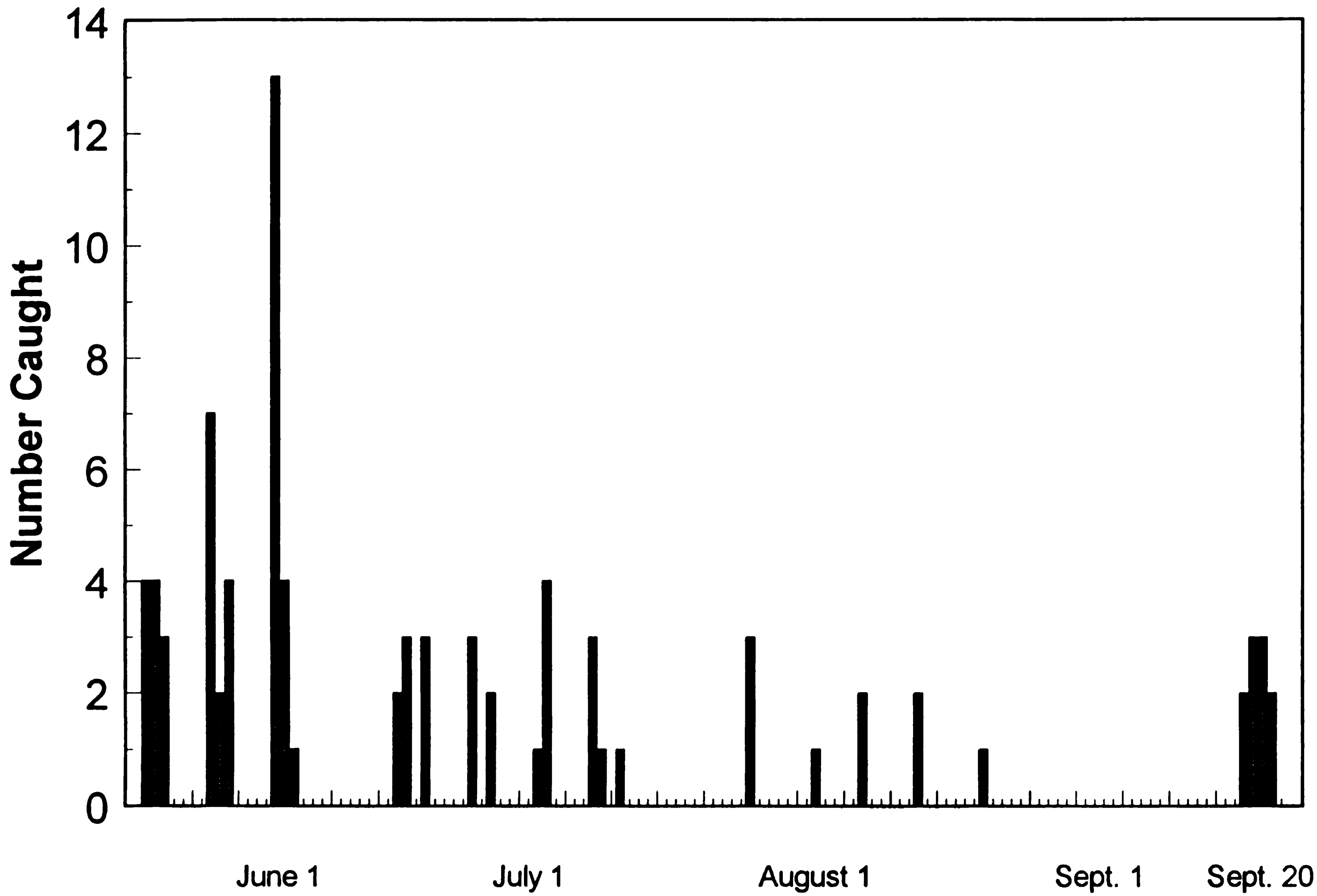



Figure 13. Number of brook trout caught each day at Site 3 in 1986.

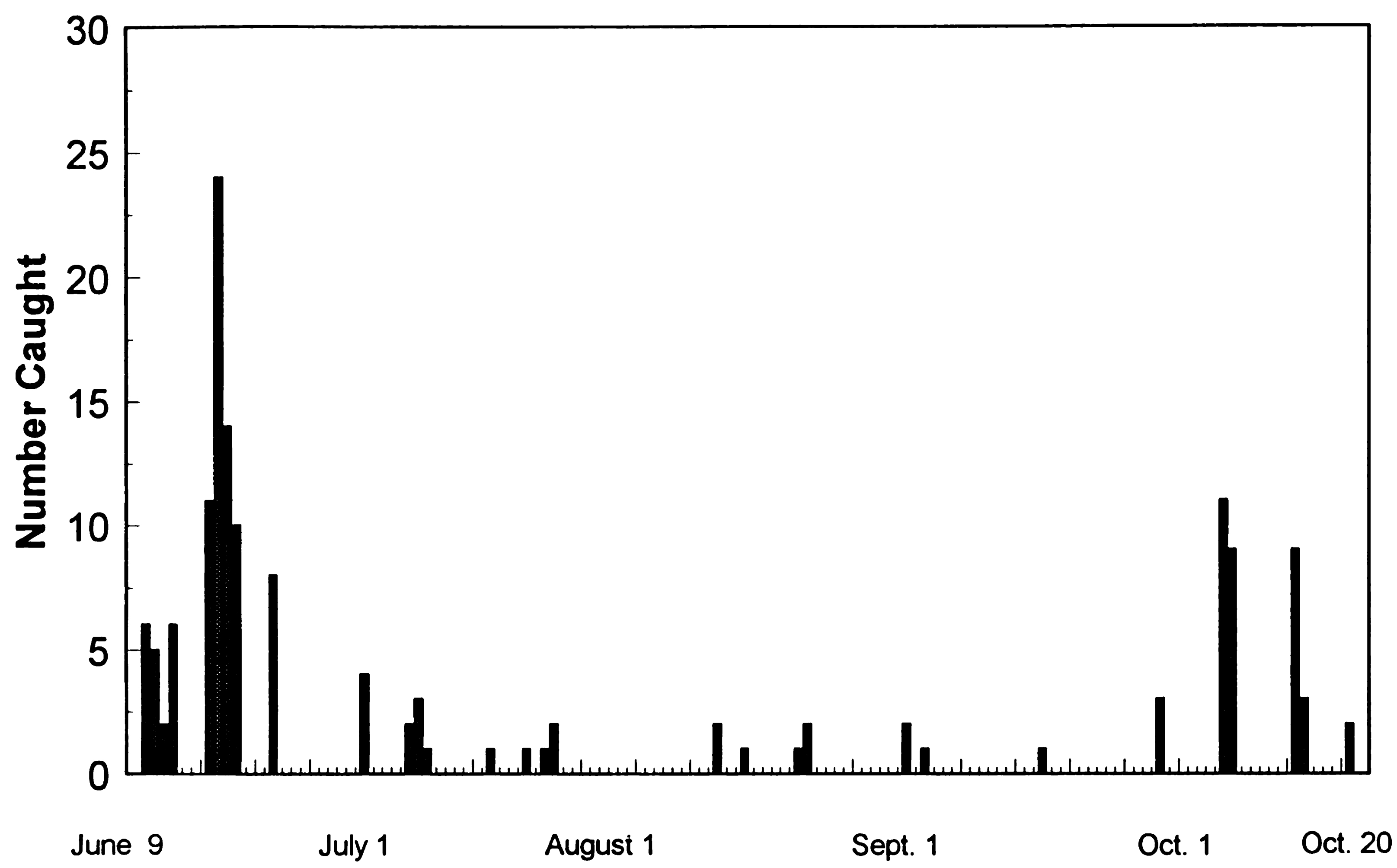



Figure 14. Number of brook trout caught each day at Site 3 in 1987.

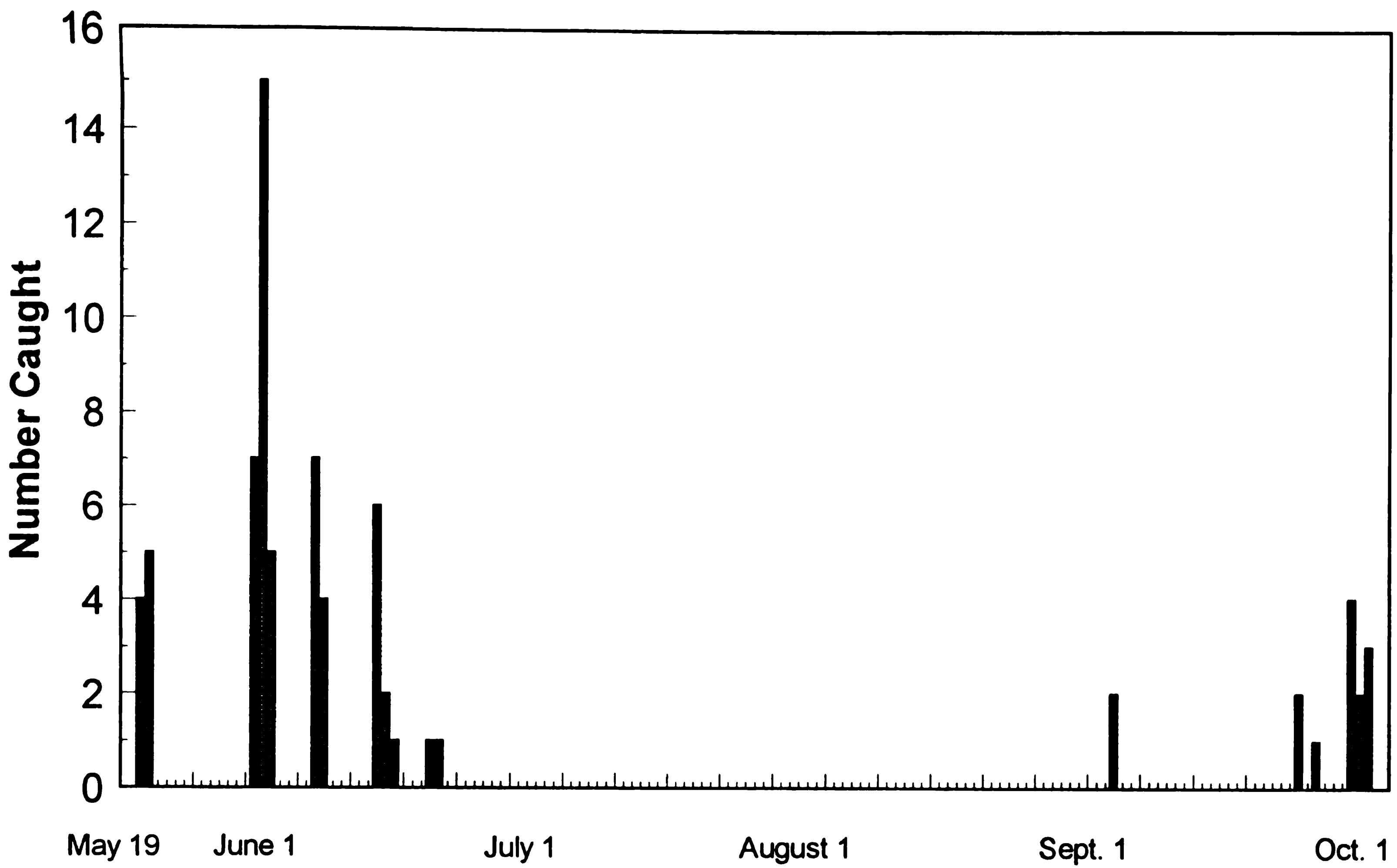



Figure 15. Number of brook trout caught each day at Site 3 in 1988.

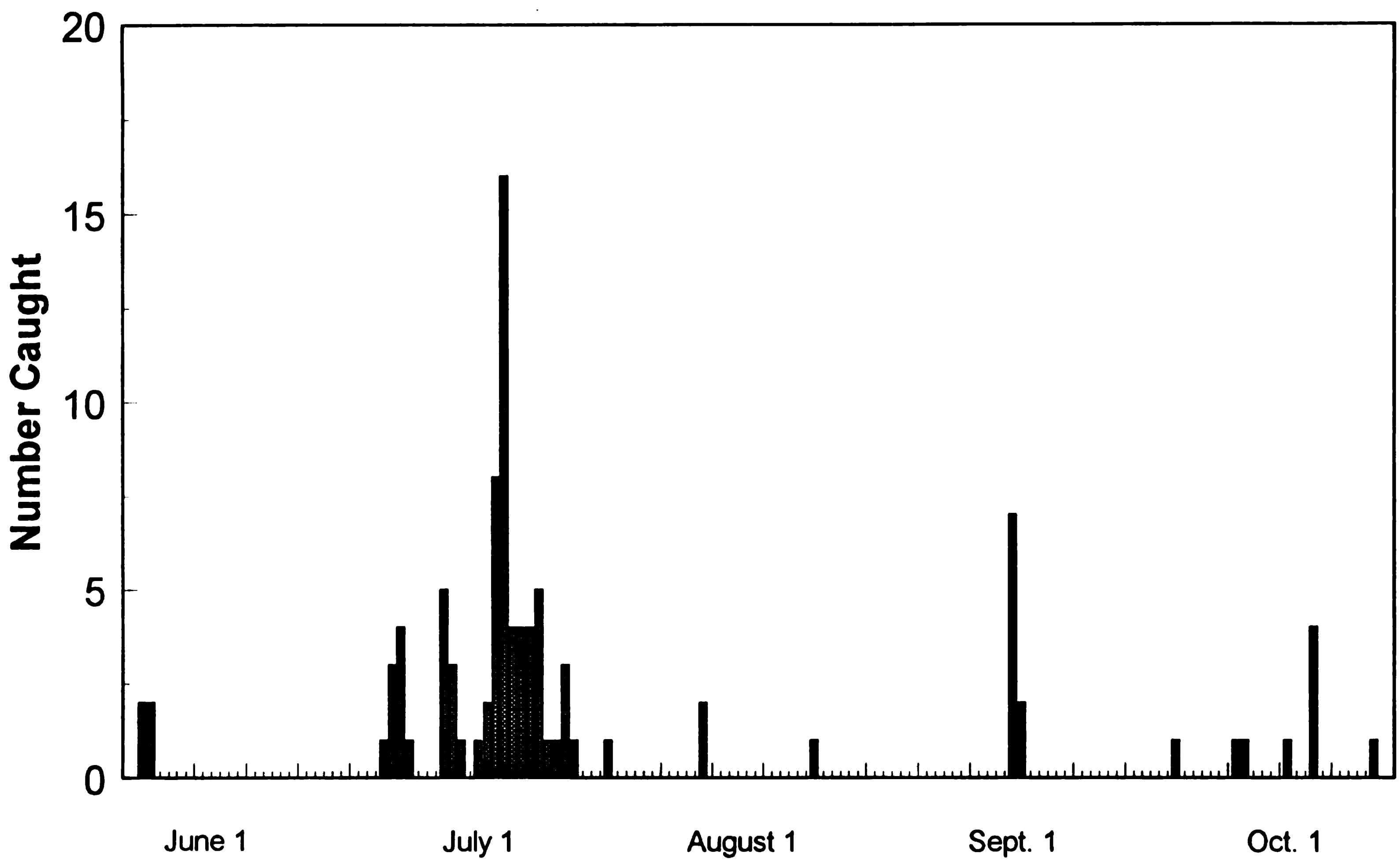



Figure 16. Number of brook trout caught each day at Site 3 in 1989.

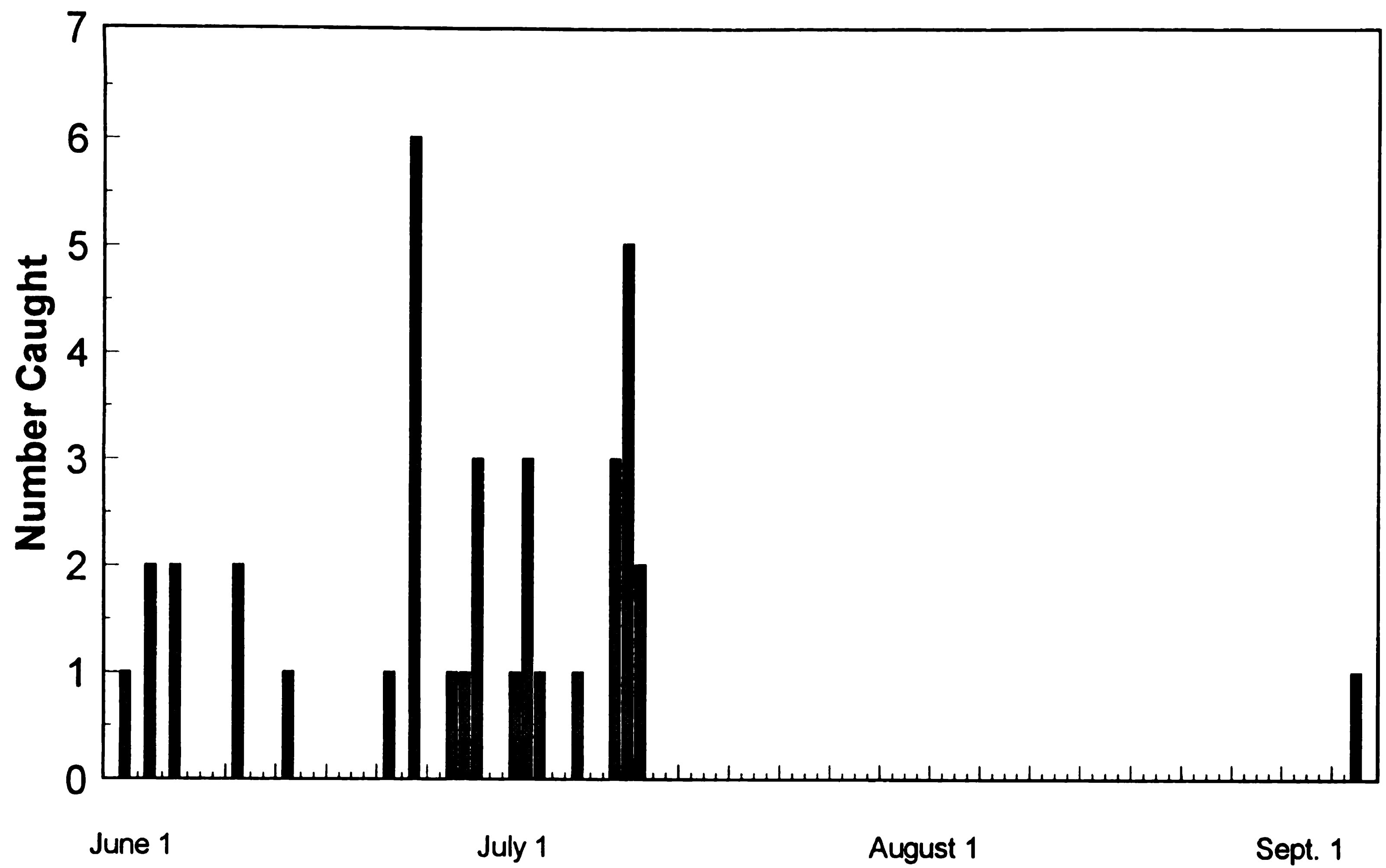



Figure 17. Number of brook trout caught each day at Site 3 in 1990.

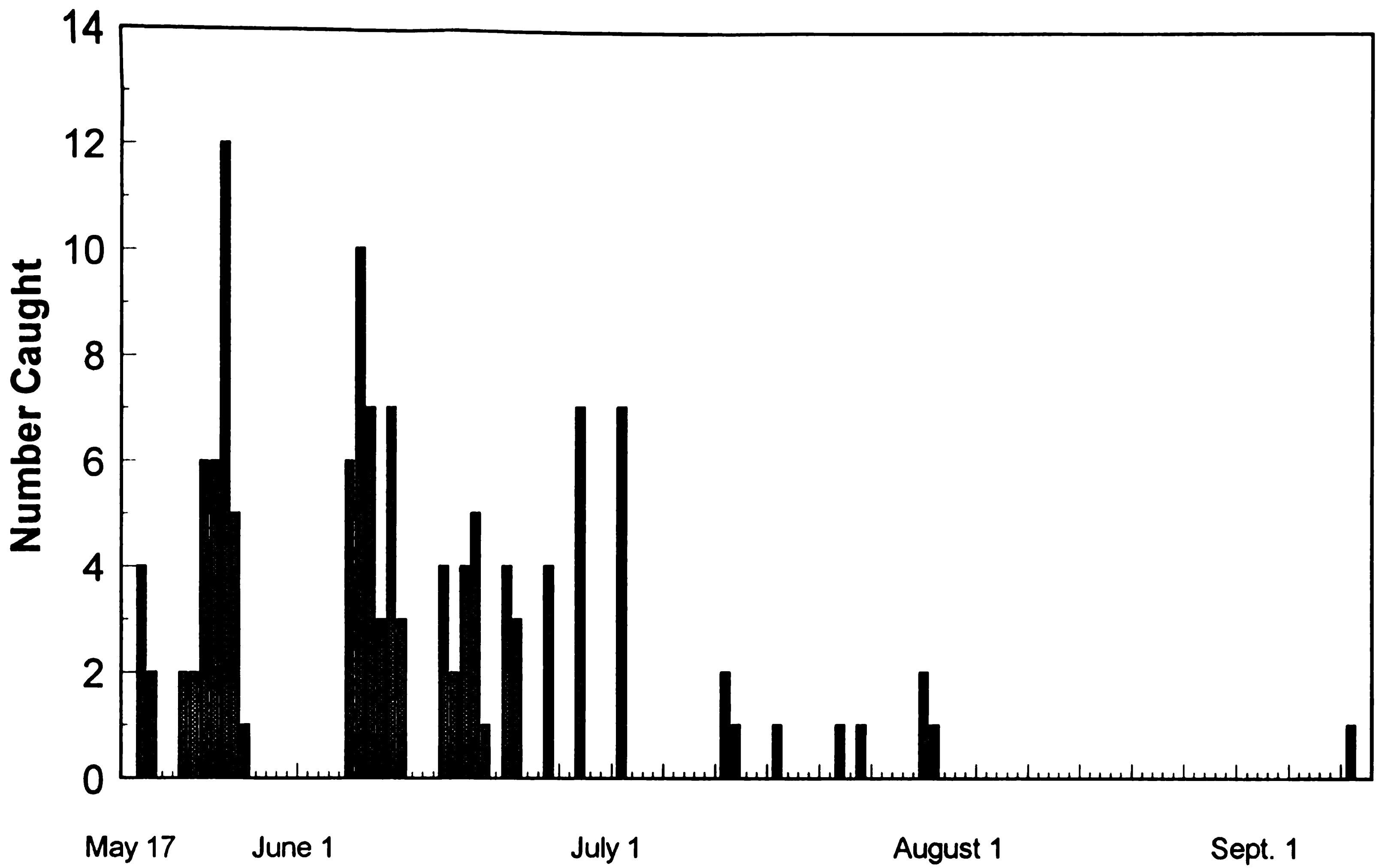



Figure 18. Number of brook trout caught each day at Site 3 in 1991.

**Appendix II**

Appendix II

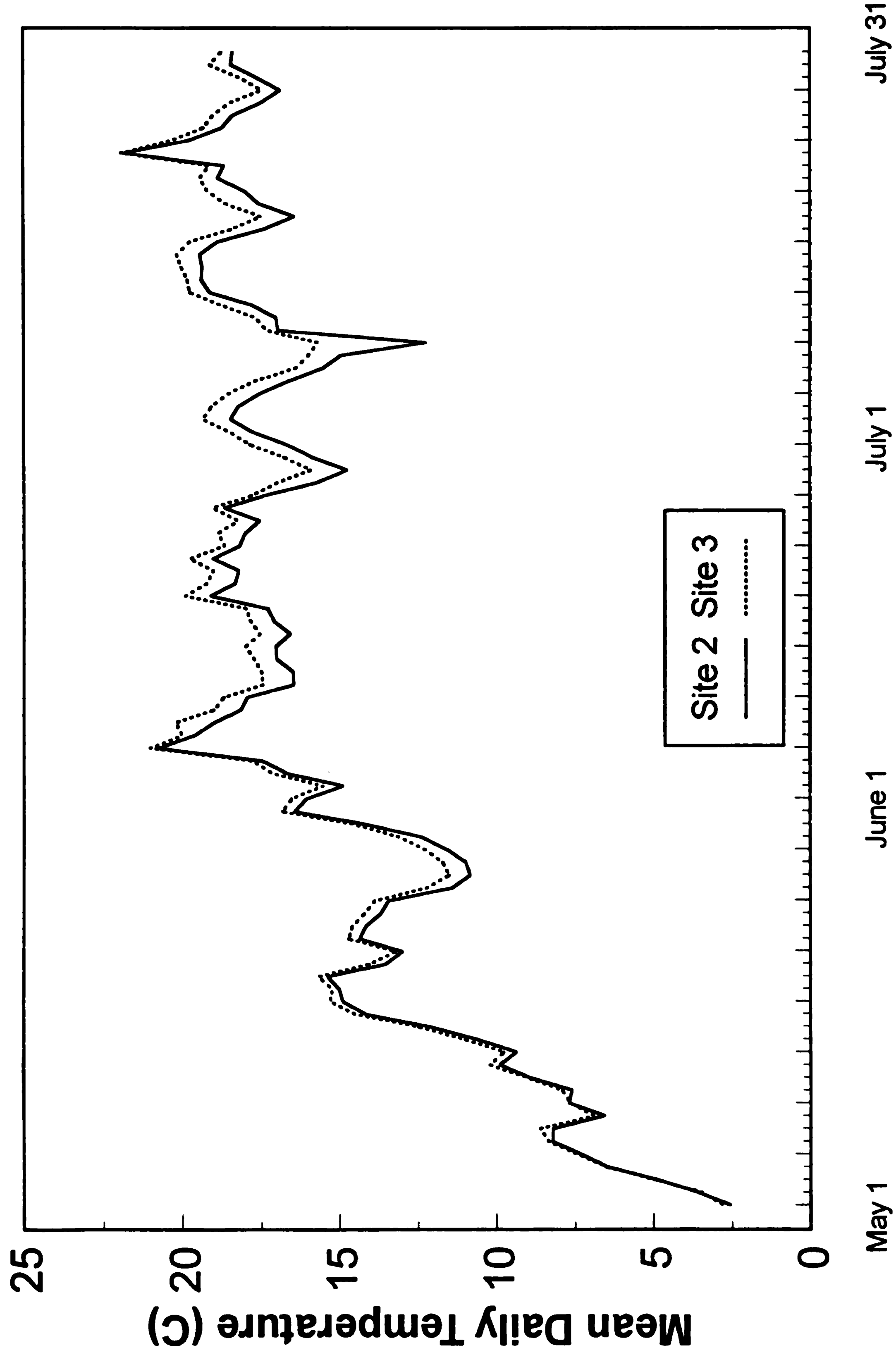



Figure 19. Mean daily temperature at Sites 2 and 3 on the Ford River in 1984.

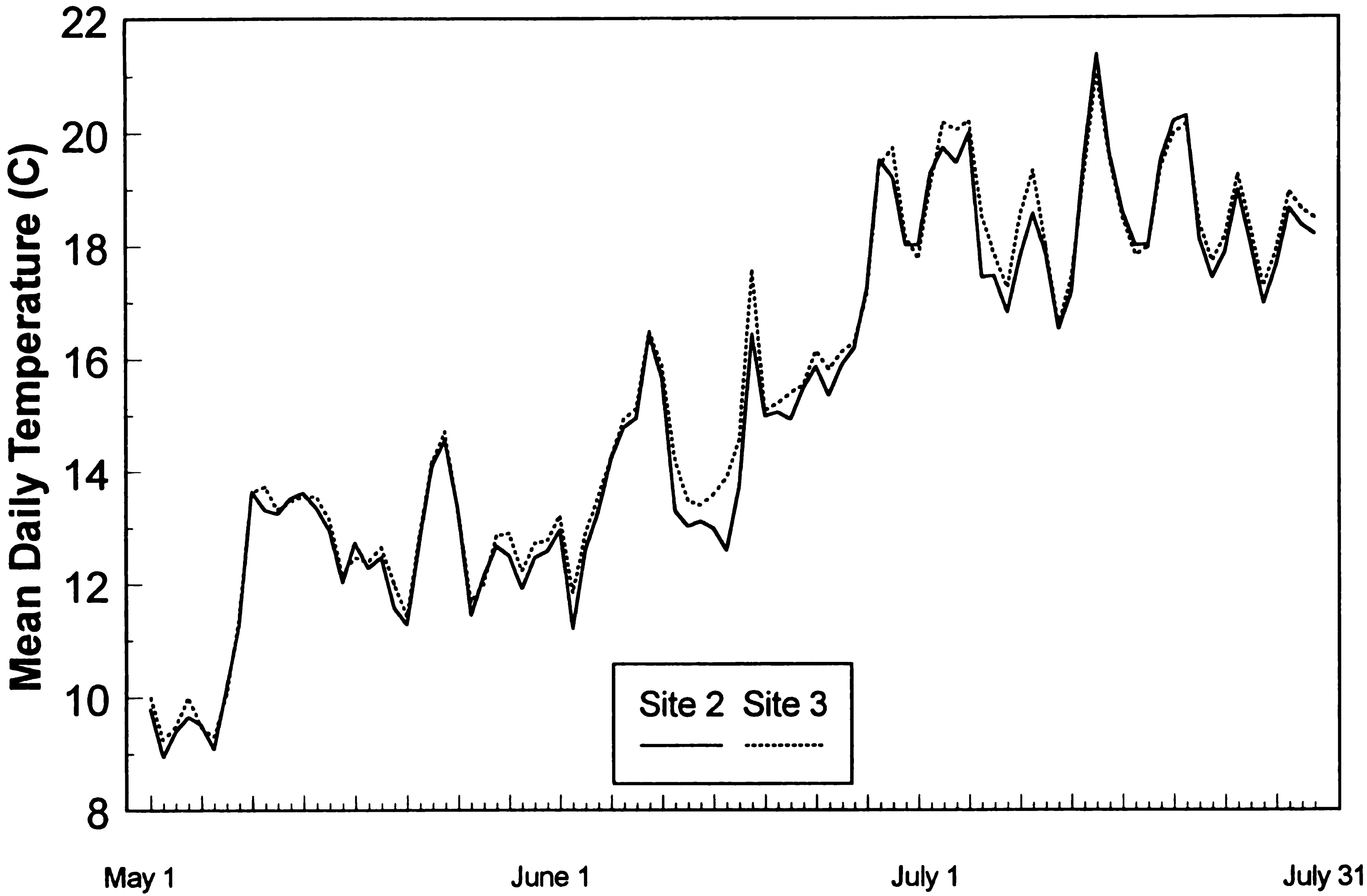



Figure 20. Mean daily temperature at Sites 2 and 3 on the Ford River in 1985.

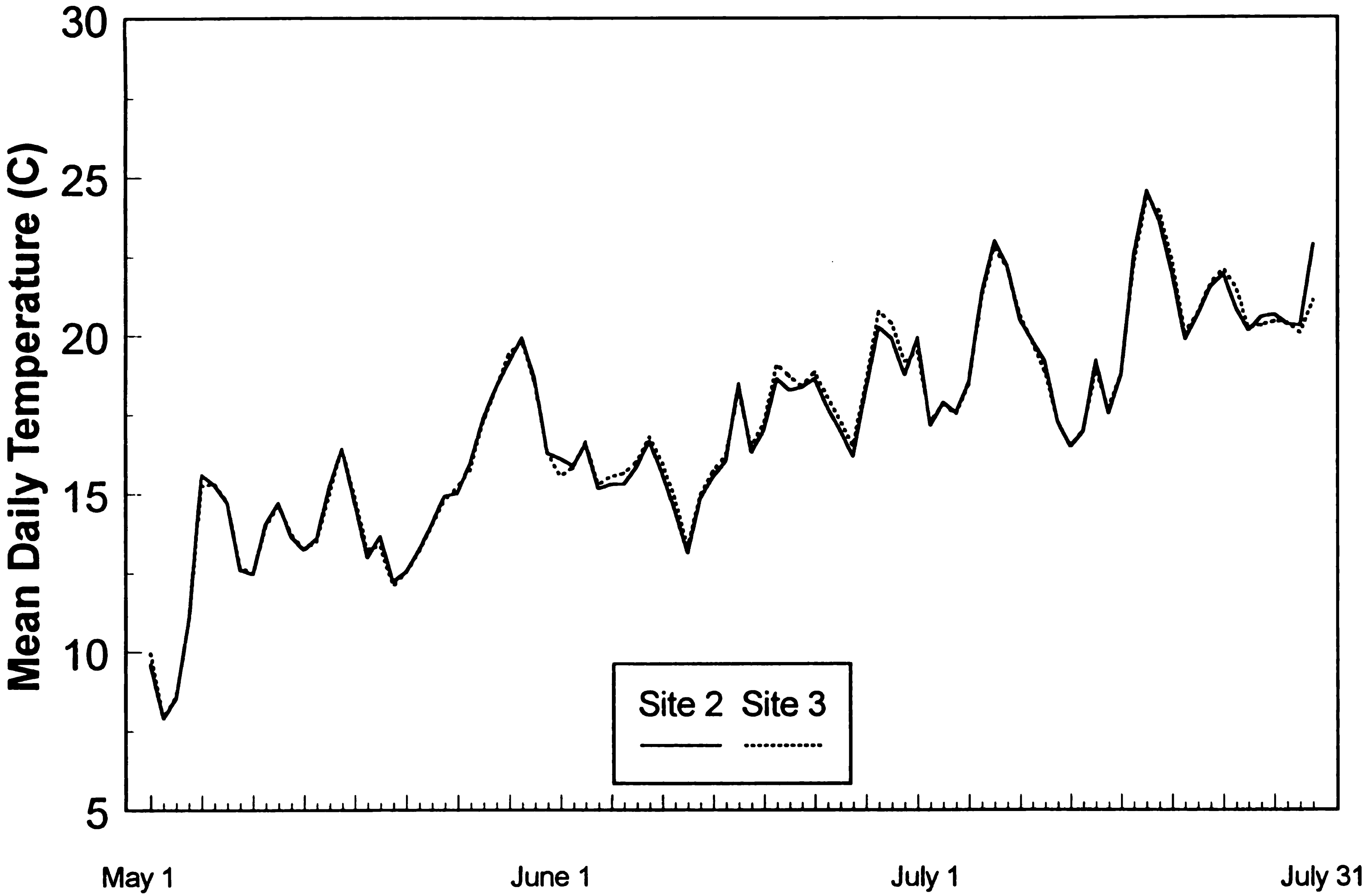



Figure 21. Mean daily temperature at Sites 2 and 3 on the Ford River in 1986.

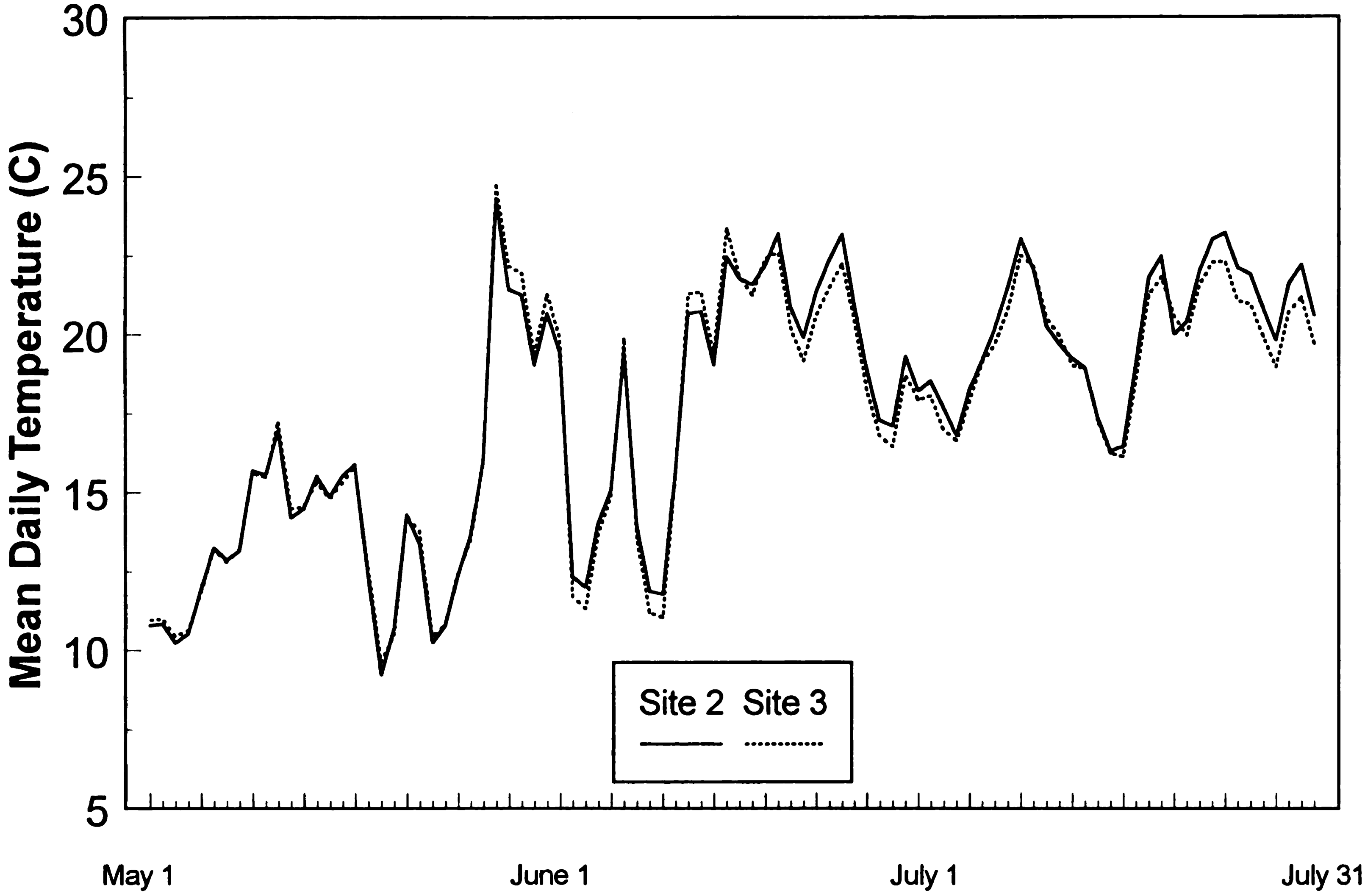



Figure 22. Mean daily temperature at Sites 2 and 3 on the Ford River in 1987.

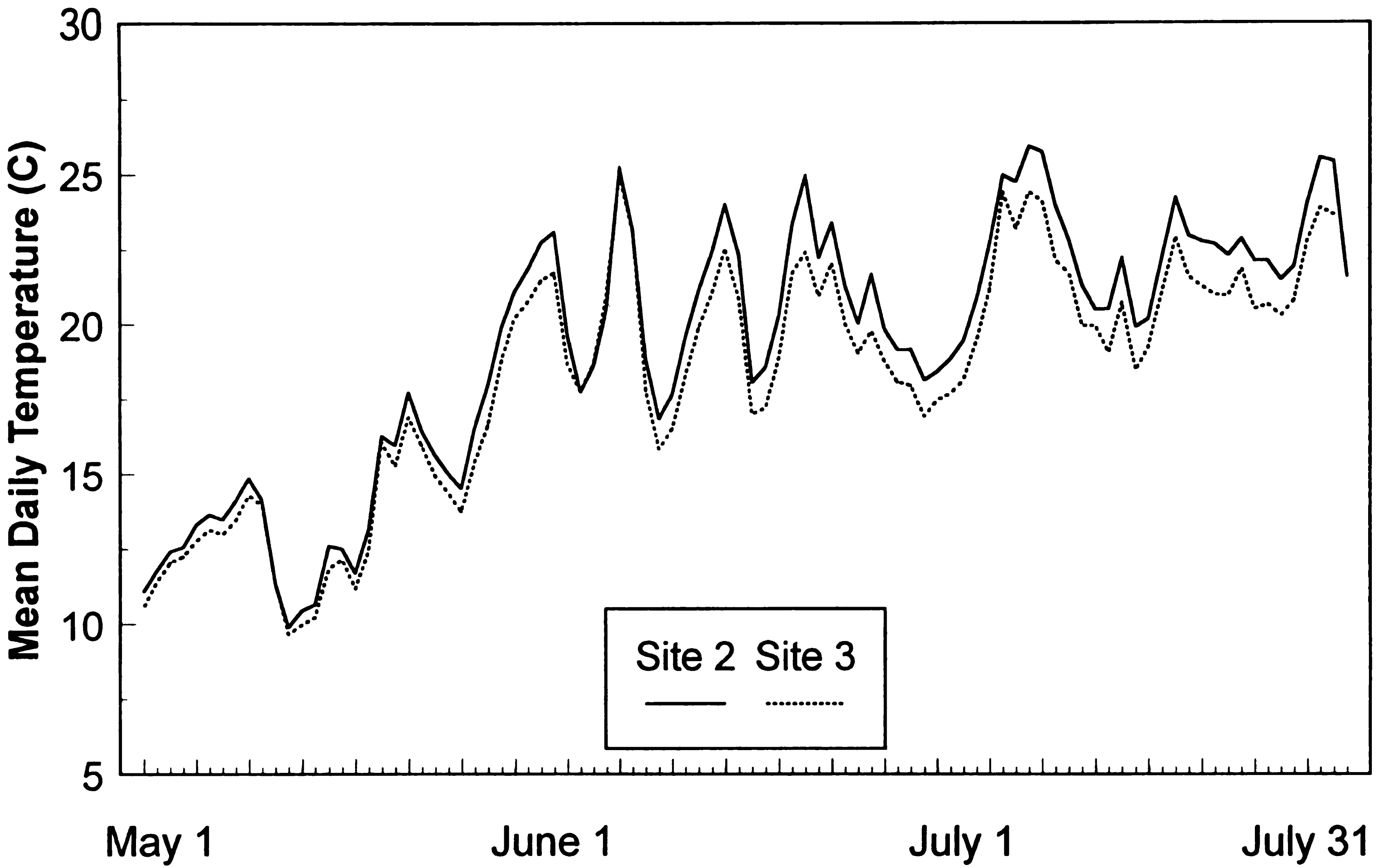



Figure 23. Mean daily temperature at Sites 2 and 3 on the Ford River in 1988.

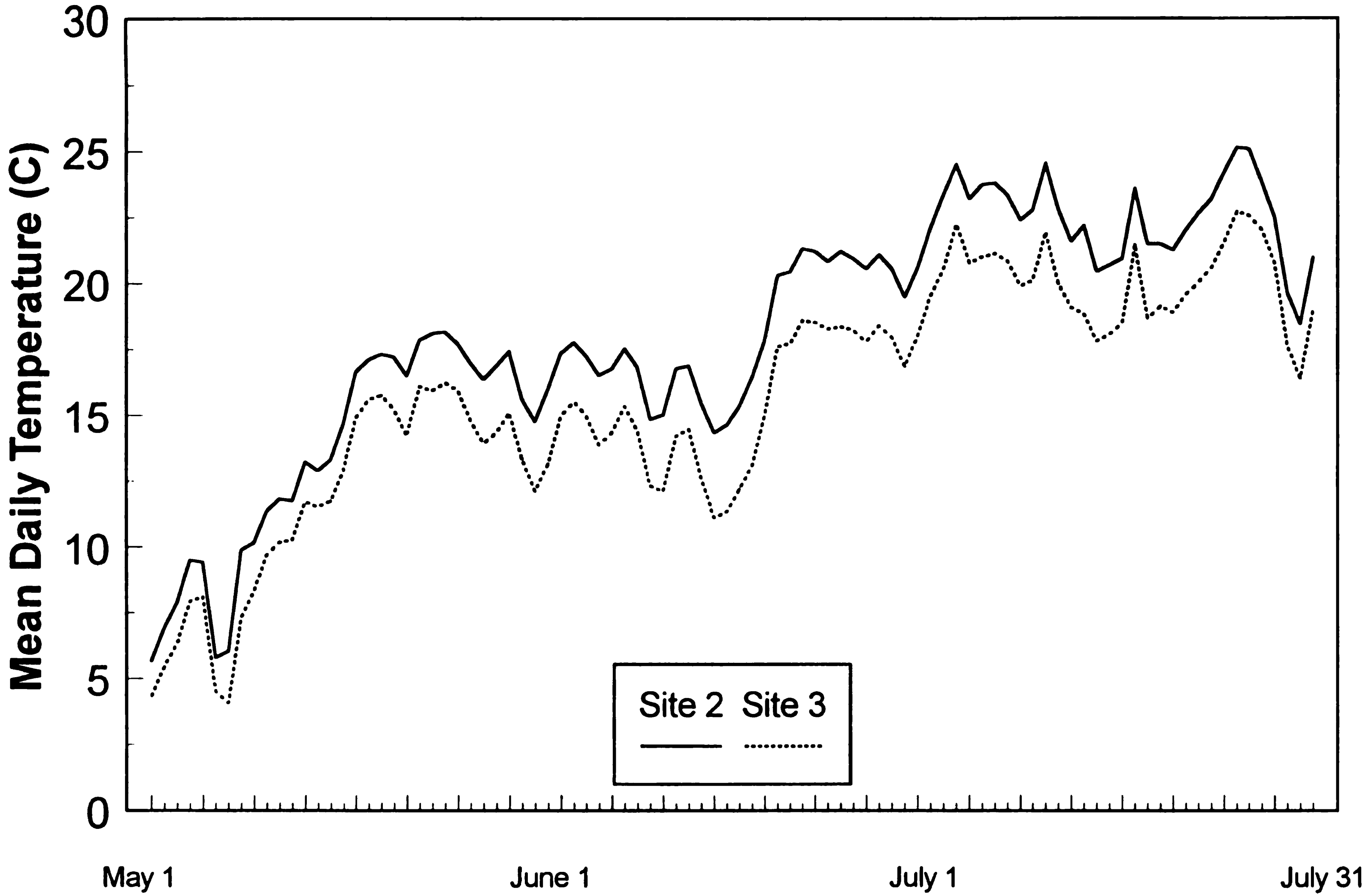



Figure 24. Mean daily temperature at Sites 2 and 3 on the Ford River in 1989.

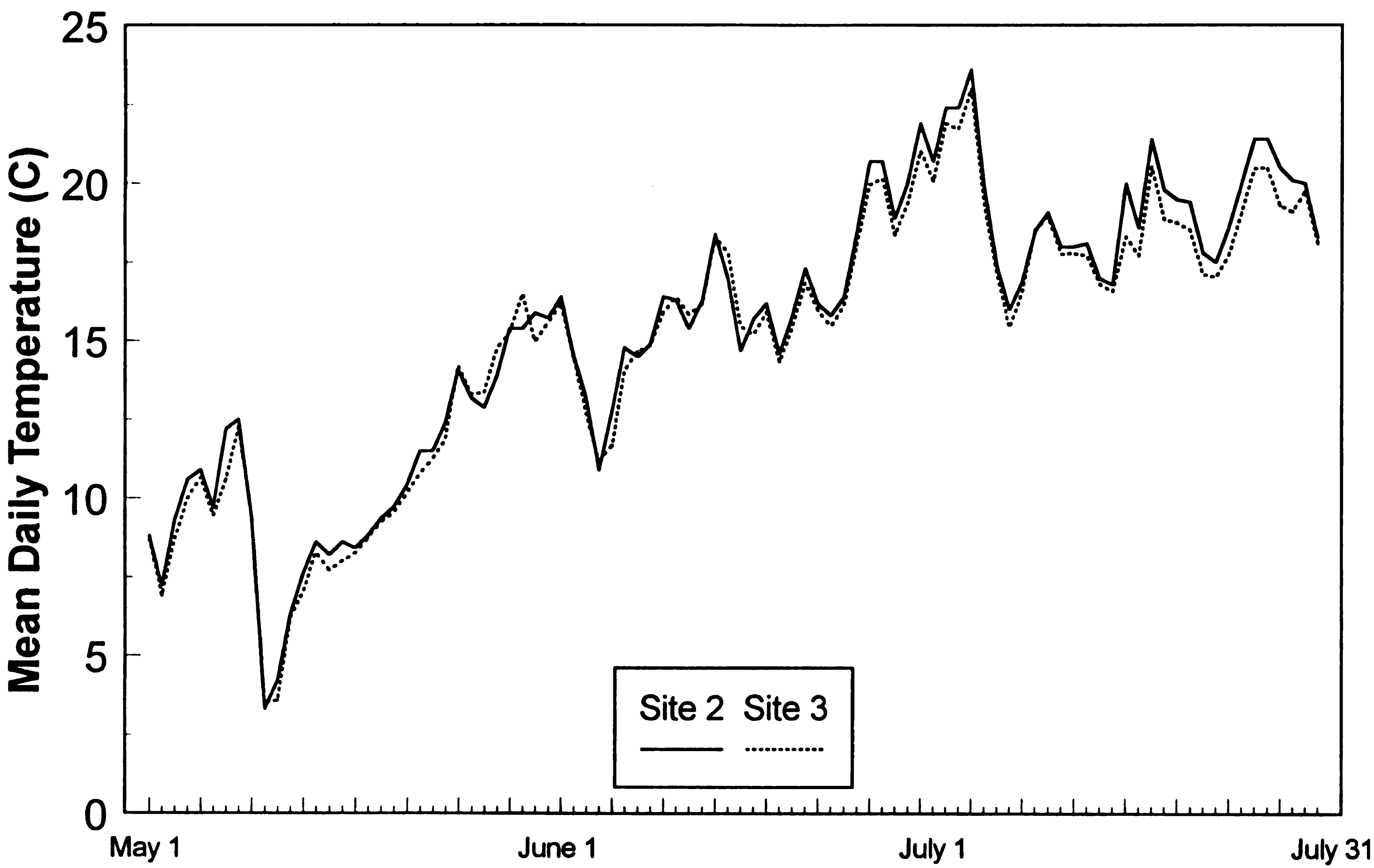



Figure 25. Mean daily temperature at Sites 2 and 3 on the Ford River in 1990.

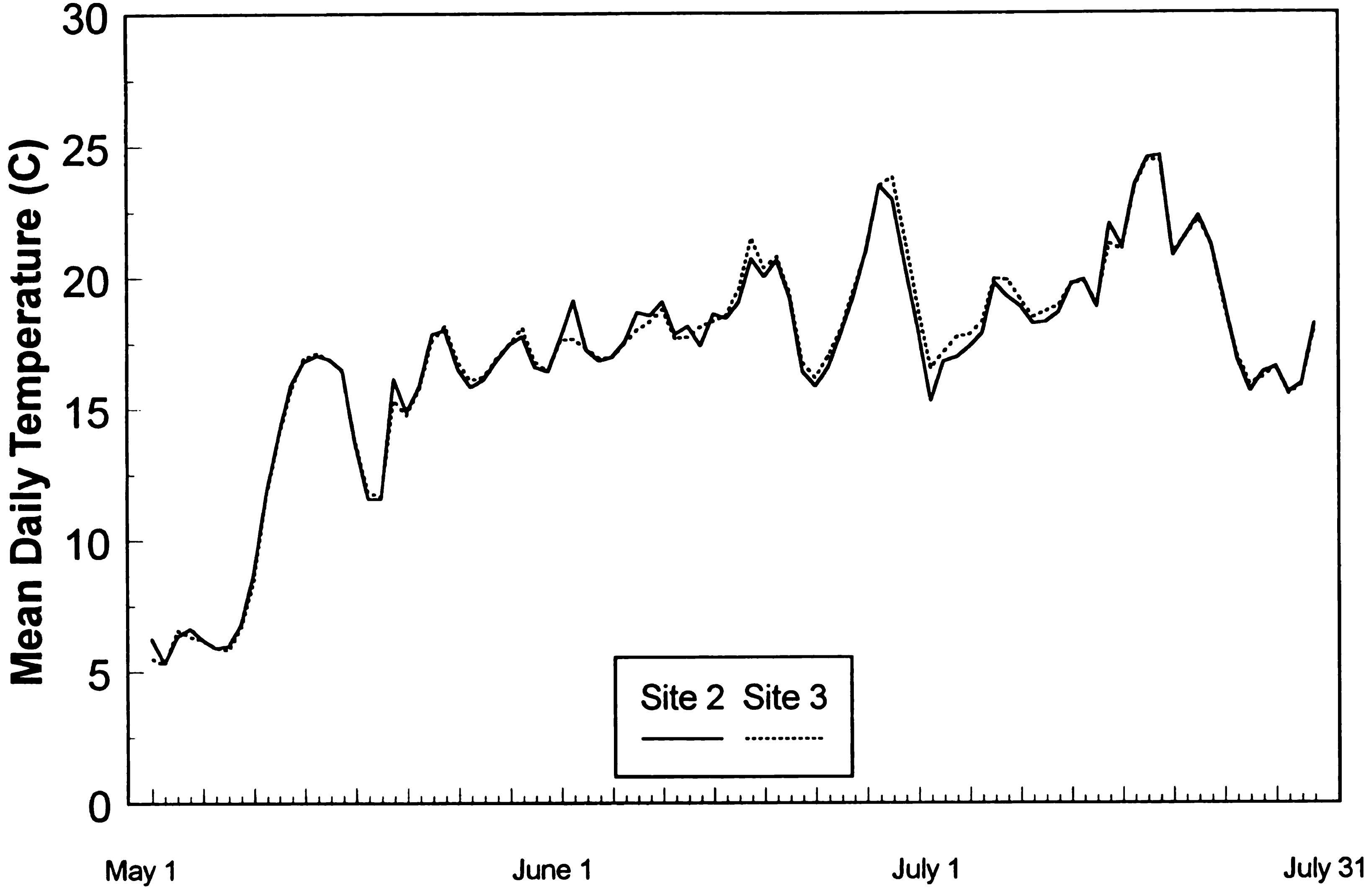



Figure 26. Mean daily temperature at Sites 2 and 3 on the Ford River in 1991.

# Appendix III

Appendix III

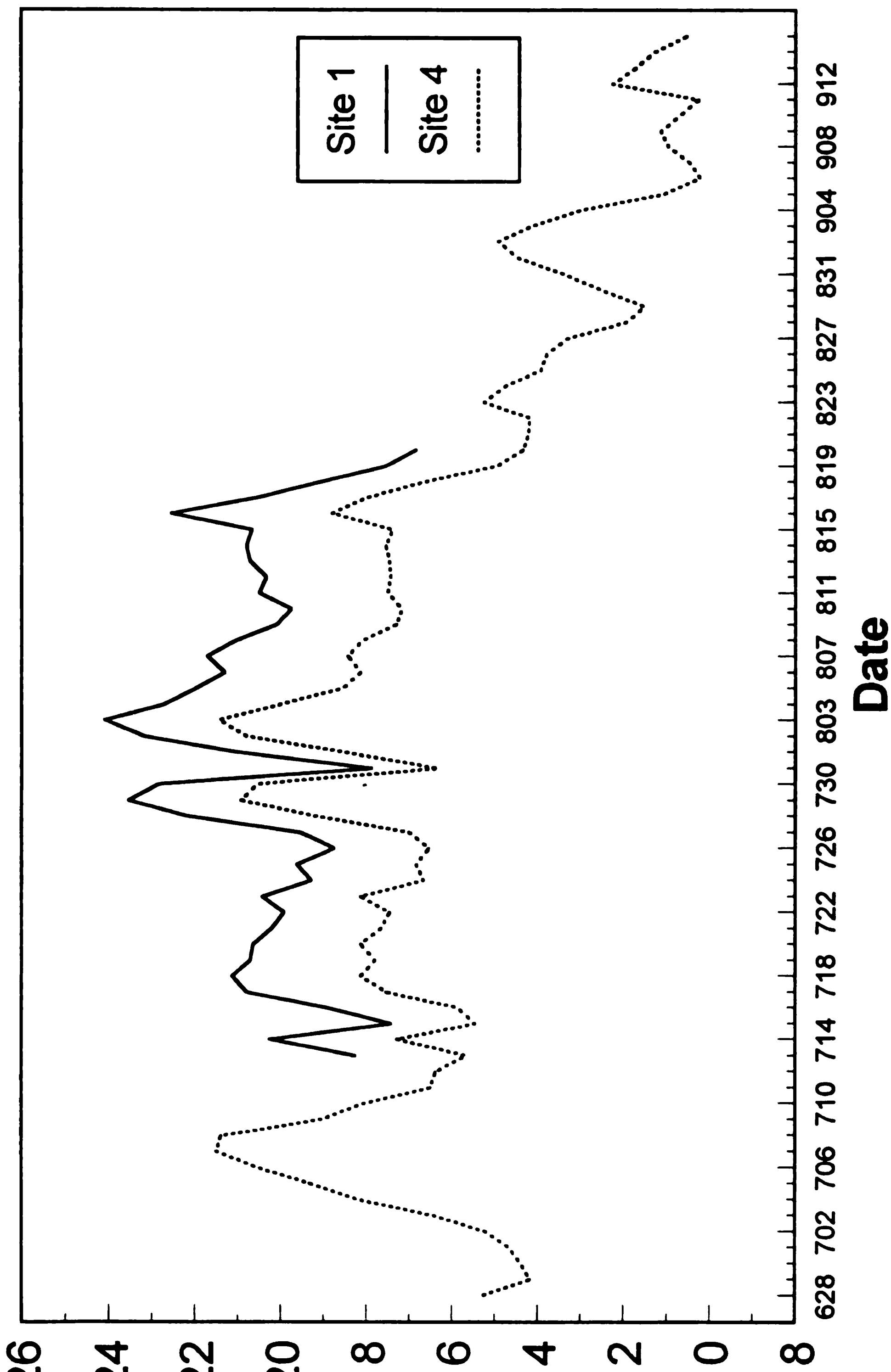



Figure 27. Mean daily temperature calculated on a weekly basis at Sites 1 and 4 on the Ford River in 1988.

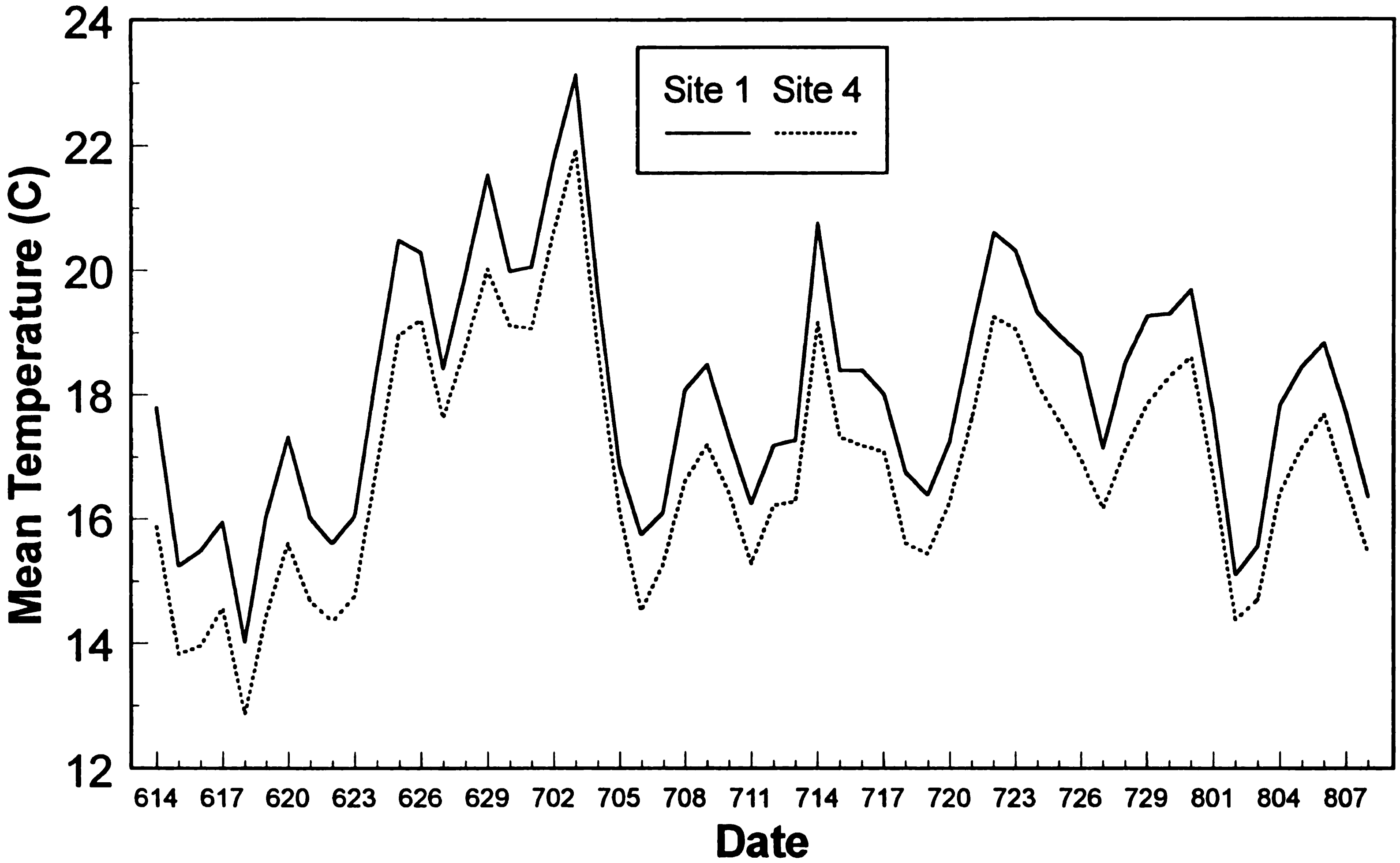



Figure 28. Mean daily temperature calculated on a weekly basis at Sites 1 and 4 on the Ford River in 1990.

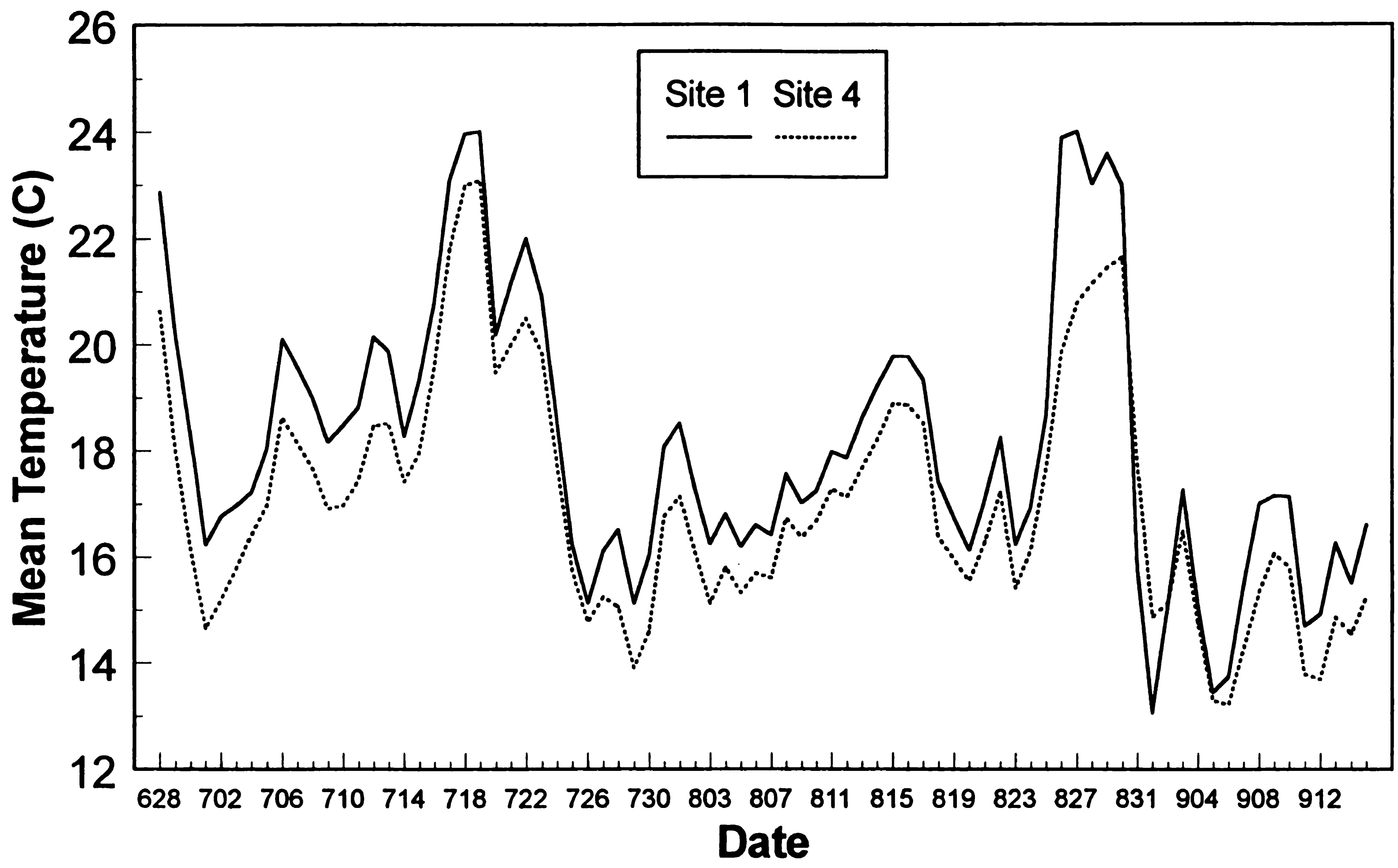



Figure 29. Mean daily temperature calculated on a weekly basis at Sites 1 and 4 on the Ford River in 1991.