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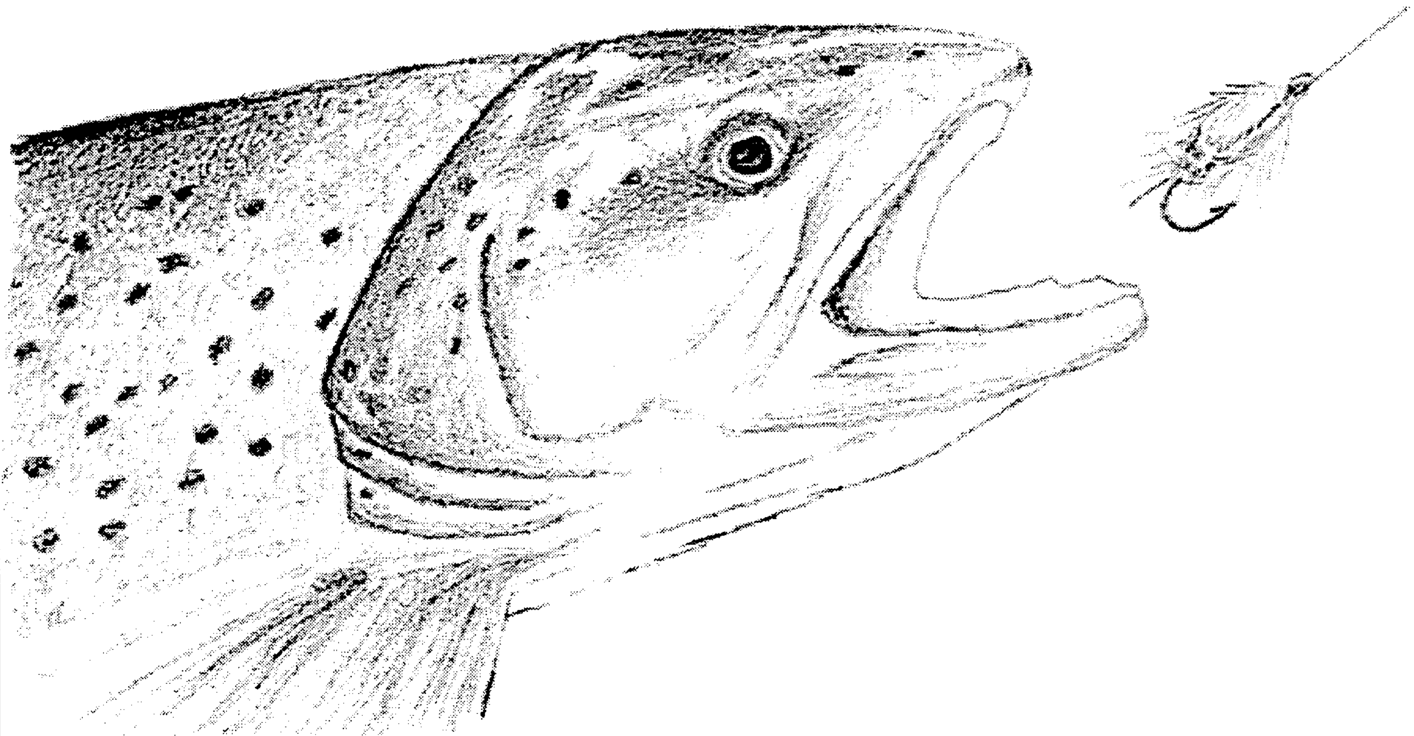

STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES

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Recruitment of Brown Trout in the South Branch of the Au Sable River, Michigan in Relation to Stream Flow and Winter Severity

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Abstract.-We monitored brown trout *Salmo trutta* populations at four 0.5-0.7 hectare sampling stations in the South Branch of the Au Sable River for 16 years between 1974 and 1993. We used linear regression analysis to search for empirical relationships between recruitment (annual abundance of age-0 brown trout) and measures of stream flow (for example, discharge during spawning, incubation, and emergence periods) and winter severity (for example, number of days air temperature was below -10 C, 20 C, 25 C, or 30 C). We found recruitment was inversely related to mean daily flows during specific 30-day periods in the spring, the dates of which varied slightly between stations. The period giving the best statistical fit to recruitment was 6 April to 5 May for the station farthest downstream ($r^2 = 0.82$), and 13 April to 12 May for the other stations. These periods seem to correspond well with the estimated times fry would enter the free-feeding stage of development. Year class strength appeared affected by both the pattern and magnitude of discharge during the 30-day periods, perhaps because multiple peaks in discharge were more likely to impact more fry during a vulnerable stage of development. We could not find statistically significant relationships between recruitment and stream flow during other periods of the year, including brown trout spawning and egg incubation periods (mid-September through March). We did not find a statistically significant relationship between recruitment and any measure of winter severity.

Past management of fisheries in prime trout waters of the Au Sable River system included controlling and removing sediment, building stream improvement structures, and applying restrictive angling regulations. The objective was to increase abundance and catch of trout, particularly larger ones. Nevertheless, we actually observed a decrease in brown trout *Salmo trutta* abundance in some sections of the South Branch, Main Branch, and North Branch of the Au Sable River over the last 20 years (Clark and Alexander 1992). Reduced trout abundance coincided with reduced recruitment of young and increased natural mortality of adults, but did not relate to changes in fishing mortality (Clark and Alexander 1985, Clark and Alexander 1992).

Recruitment of young for many stream fishes is adversely affected by the magnitude and timing of seasonal changes in flow (Elwood and Waters 1969; Seegrist and Gard 1972; Anderson 1983; Ottaway and Forrest 1983; Holmes 1984; Nelson 1984; Harvey 1987; Erman et al. 1988; Kondolf et al. 1991; Clark 1992). The Au Sable River has relatively stable water flow, but variations do occur seasonally and from year to year. Likewise, recruitment of brown trout is relatively stable, but not constant. Our first hypothesis was that stream flow and recruitment were related. For example, high or low stream flow during adult spawning, egg incubation, or fry emergence could be detrimental to recruitment. Thus, trends in water flow characteristics caused by changing land use or climate could cause trends in brown trout populations.

Recruitment of young can be affected by winter severity. Winter conditions can be detrimental to egg and fry survival in streams (Nelson 1984, Dechant and West 1985), and winters are relatively severe in the Au Sable Basin. Our second hypothesis was that winter severity and brown trout recruitment were related. For example, extreme cold could freeze or reduce the survival of developing embryos in redds or ice scouring could destroy redds. Thus, trends in winter severity might cause trends in brown trout populations.

The purpose of this study was to examine the effect of stream flow and winter severity on recruitment of brown trout. We focused our efforts on the South Branch of the Au Sable River, because relatively long time series of data were available for the stream.

Methods

The South Branch of the Au Sable River is a coldwater river that flows through forested areas near the north-central portion of Michigan's lower peninsula (Figure 1). The South Branch originates as the outlet of Lake St. Helen, a 971 hectare natural lake. Within about 1.3 km it flows into 38 hectare Mud Lake, the level of which is controlled by a dam. From below the dam to the confluence of Robinson Creek (just upstream from Roscommon), summer water temperatures are generally higher than the optimal range for trout. Downstream from Robinson Creek, the stream receives considerable groundwater input. At Chase Bridge (the upstream end of our study area), it reaches 55% of its terminal flow, and water temperatures are suitable for trout year-round. In the next 16 km between Chase and Smith bridges, the river acquires another 30% of its terminal flow primarily from groundwater input (Coopes 1974). This groundwater moderates water temperatures both summer and winter. Mean daily water temperatures at Smith Bridge was 0.75 C colder than at Chase Bridge throughout July and August 1993. Temperatures at Smith Bridge during winter are probably slightly warmer than those at Chase Bridge, but no data exist for a direct comparison in winter.

Continuous discharge records were available from a United States Geological Survey gauge at Smith Bridge from October 1966 to September 1989, and October 1990 to September 1993. During this period the 10% exceedance flow was 10.2 m^3/s (360 cfs) and the 90% exceedance discharge was 3.8 m^3/s (135 cfs). The highest and lowest daily mean discharges were 31.4 m^3/s (1110 cfs) and 2.8 m^3/s (100 cfs), respectively.

We focused our analysis on the river section between Chase and Smith Bridges (Figure 1). Brown trout abundance estimates were conducted for 16 years at four index stations, Chase Bridge (0.52 hectare), Marlabar (0.56 hectare), Dogtown (0.72 hectare), and Smith Bridge (0.61 hectare). The Dogtown station was 244-m long and had a mean width of 30 m. The other three stations were each 274-m long and mean widths ranged from 19 to 22 m. Abundance was estimated using the Bailey mark-and-recapture method (Bailey 1951) during fall 1974-77, 1981-85, and 1987-93. Estimates were stratified by 2.54-cm length groups. Trout were captured using DC electrofishing gear. With few exceptions, sampling was done in early October each year. Representative samples of trout were aged by reading scales, and population estimates by length group were apportioned into estimates by age group.

Least-squares regression was used to identify relationships between brown trout recruitment, defined as estimated abundance of age-0 fish, and a number of independent variables. Abundance of age-0 brown trout from annual estimates were treated as a single observations of recruitment for a given year at a given station. Those observations for all 16 years were used as dependent variables at each station for all regressions in our analysis. Abundance estimates for each station were treated separately and were not pooled or combined in any way, that is, separate regressions were computed by station for each independent variable. Data transformations were tested in some cases to attempt to improve regression models when relationships appeared curvilinear. Plots of residuals were examined to judge adherence to the normality assumption. All statistical analyses were done using SPSS for Windows Release 6.0. A full list of independent variables tested is presented in Appendix 1. The rational for choosing independent variables to test is described below.

Stream flow could affect several critical periods in the life history of brown trout, and these periods could be relatively brief in duration. The timing of critical periods might also be different in different parts of the South Branch. For example, they could depend on water temperature which varies along the course of the river. We knew that brown trout fry emerged from the gravel, absorbed their yolk sack, and began eating food in early spring, but we did not know the exact timing of those events. Therefore, we examined relationships between brown trout recruitment and mean daily flows for a number of different date intervals (Appendix 1). We computed separate regressions between recruitment and mean flows for intervals that were 15-, 20-, and 30-days long between 1-April and 30-June of each year. We also computed regressions between recruitment and the highest 7-day average flows, as well as, between recruitment and highest individual daily flows occurring from 1-April through 30-May of each year. Smith Bridge was the only station where flow was actually measured. We assumed flows at the other stations were proportional.

Stream flow during spawning and incubation could also be critical in determining year class strength. We tried to relate brown trout recruitment to stream flow variables (maximum, minimum, and mean monthly flows) during the period when spawning and embryo development was expected to take place (mid September through March - Appendix 1). Based on personal observations of northern Michigan trout streams and reports by other investigators, we expected that most spawning would occur between mid-October and mid-November (Shetter 1944; Hansen 1975). Therefore, as independent variables for regression analysis, we computed annual mean flows for 20-day intervals between 16 September and 14 December (the period when we expected spawning to occur).

Severe winter weather conditions, particularly those that lead to significant ice formation in rivers, are often cited as causes of poor reproductive success. We used air temperature data collected at the City of Grayling weather station to derive two sets of independent variables to represent winter severity during incubation. We assumed air temperature would reflect winter severity better than water temperature, because it would be more representative of severe ice conditions. For example, severity of anchor and frazil ice would most likely occur in proportion to air temperature, which can fall well below 0 C, while temperature of flowing water cannot fall much below 0 C. Therefore, for our first set of winter severity variables, we determined the number of days when minimum air temperatures fell below -10 C, -20 C, -25 C, and -30 C for each month from November through March. Additional variables indicating the number of days when minimum air temperatures fell below these thresholds over longer intervals were also computed (for example, November-February, December-March, and so on). A second set of winter severity variables were computed as cumulative cooling degree days (sum of deviations from a given temperature) for individual months and combinations of months from November-March. Cooling degree days were determined for mean daily base temperatures of 0 C, -10 C, and -15 C.

Results

Brown trout recruitment was most highly correlated with mean daily flows during periods in the spring. Mean daily flows for 30-day intervals gave higher correlations than 15- or 20-day intervals. Dates of intervals giving the best fits varied slightly between stations, with 6 April to 5 May at Smith Bridge and 11 April to 10 May at the other three stations. The interval giving the best fit was earliest in the year at the station farthest downstream. The specific relationship (Figure 2) at Smith Bridge station was:

$$N_0 = 2996 - 1038 \ln(X),$$
$$r^2 = 0.82, \quad P < 0.0001,$$

where N_0 is the number of age-0 brown trout present during the fall following the flow period, X is the mean discharge in m^3/s from 6 April - 5 May, r^2 is the coefficient of determination, and P is the significance level of the F statistic for the regression equation. The natural log transformation of mean discharge improved the R^2 value for the relationship between flow and recruitment by 0.08 and reduced variation around the regression line.

Log-transformation of flow variables did not significantly improve statistical fits at the Chase Bridge, Marlabar, and Dogtown stations. The best fitting relationship (Figure 3a) at Chase Bridge was:

$$N_0 = 1495 - 88\,X,$$
$$r^2 = 0.47, \quad P = 0.0047,$$

where X is mean discharge in m^3/s from 13 April - 12 May.

At Marlabar, the best fitting relationship (Figure 3b) was:

$$N_0 = 1297 - 74\,X,$$
$$r^2 = 0.40, \quad P = 0.0109,$$

where X is mean discharge in m^3/s from 13 April - 12 May.

At Dogtown, the best fitting relationship (Figure 3c) was:

$$N_0 = 515 - 33\,X,$$
$$r^2 = 0.44, \quad P = 0.0067,$$

where X is mean discharge in m^3/s from 13 April - 12 May.

Both the frequency and magnitude of high mean daily flows during the spring appeared to account for deviations of some year classes that were more or less abundant than predicted by the regression models. Two of the largest year classes produced during the study period were associated with unusually low and stable mean daily flows during the spring (Figure 4). The 1977 year class was the largest measured at 3 of 4 stations over the sampling period and the 1987 year class was much larger than average at the Chase and Smith Bridge stations. By contrast the lowest year class of record (1991) was associated with both high mean flows and 3 short periods when discharge increased rapidly (Figure 4). The highest discharge of record for the May and June period corresponded with an unauthorized draw down of Lake St. Helen during late May and early June 1991.

Stream flow during the spawning and incubation periods did not strongly relate to brown trout recruitment. However, stream discharge during these periods rarely exceeded

8.5 m^3/s (300 cfs), whereas flows of this magnitude or greater were common during April.

Our measures of winter severity did not strongly relate to brown trout recruitment. The correlations between the number of days that air temperatures fell below -10 C, -20 C, -25 C, and -30 C were generally low and statistically insignificant $P > 0.05$. Similar results were obtained from analyses of correlations between recruitment and cooling degree days.

Discussion

Recruitment of brown trout in the South Branch Au Sable was strongly related to the pattern and magnitude of stream flow in early spring. Our empirical analysis cannot determine *how* stream flow affects recruitment of brown trout, but one possible mechanism would be that mortality of newly emerged fry increases as flow increases. Ottaway and Forrest (1983) showed that the rate of loss of brown trout fry from experimental channels increased substantially as fry entered the free-feeding stage, and that losses were proportionally higher as water velocity increased. Similarly, a flood that occurred before fantail darters *Etheostoma flabellare* emerged from their nests in one river had little effect on young-of-the-year abundance, whereas the same flood devastated juveniles in another stream where they had already dispersed from nests (Coon 1988).

We did not estimate fry emergence dates in the field, but stream-flow date intervals giving the best empirical fits to brown trout recruitment corresponded well to emergence times that would be predicted from incubation time models (Crisp 1981; 1988). It is well known that trout embryo development and hatching time is related to incubation temperatures (Embody 1934; Alderdice and Velsen 1978; Crisp 1981, 1988; Beacham and Murray 1990). We recorded daily mean surface water temperatures at Chase Bridge (means of hourly observations) from 15 October 1990 to 30 April 1991. These temperature data applied to Crisp's model (Crisp 1981) suggested that brown trout fry should have emerged from gravel between 20 and 30 April 1991, depending on spawning date. This is later than the best fitting date interval (13 April to 12 May), but temperatures in brown trout redds may be warmer than surface water temperatures.

Hansen (1975) observed that brown trout preferred to spawn in areas with mixes of surface and groundwater, provided that oxygen levels of the groundwater were reasonably high.

Hansen (1975) found that when surface water temperatures were 0 C, temperatures in streambed areas with brown trout redds were up to 7 C warmer. Therefore, it reasonable to assume that actual emergence dates in the South Branch could be significantly earlier than those determined from surface water temperatures due to groundwater warming of redds. For example, if we assume that mean redd temperatures were 2 C warmer than surface water temperatures from 15 October 1990 to 31 March 1991 (a time period when groundwater temperature always exceeded surface temperature), then the median predicted emergence date for eggs spawned on 15 October 1990 would be 24 March 1991, 27 days earlier than predicted from surface temperature. Similarly, median predicted emergence for eggs spawned on 1 and 15 November would be 12 and 22 April respectively. If these projections are realistic, then many newly emerged fry would have been present during the time periods when high flows appeared to negatively affect brown trout recruitment.

We noticed a tendency for weaker year classes to occur during years when there were multiple peaks in stream flow during spring. Anderson (1983) noted that gradual spring runoff enhanced fry survival. Kondolf et al. (1991) hypothesized that brown trout were more abundant than rainbow trout in river reaches they studied because high flows resulting from snowmelt during May and June occurred long after brown trout fry emerged whereas eggs of rainbow trout still in the gravel were vulnerable to scour. At both the Chase and Smith Bridge stations the 1977 and 1987 year classes, which emerged during years with low and extremely stable spring flows, were substantially larger than year classes subject to higher and more variable spring flows.

Recruitment versus stream-flow regressions gave better statistical fits for slightly later date intervals (13 April to 12 May) at Chase Bridge, Marlabar, and Dogtown than at Smith Bridge (6 April to 5 May). We think this may be related to differences in the timing of brown trout emergence at these stations. As the South Branch flows downstream, the complement of groundwater increases and Smith Bridge is the station farthest downstream. We suspect that groundwater results in warmer winter water temperatures and shorter incubation periods at Smith Bridge than the other stations.

Eggs and developing fry did not appear to be adversely affected by stream discharges that occurred between November and March in the South Branch, presumably because these flows were not high enough to significantly disrupt spawning activity, or to damage or destroy redds via scour or siltation. This contrasts with the findings of other investigators working in streams that experience severe winter floods. Destruction of trout redds by winter or spring floods has been previously reported for brown trout (Allen 1951; Anderson 1983). Similar findings regarding gravel scour during winter floods and year class failure have also been reported for brook trout (Elwood and Waters 1969; Seegrist and Gard 1972; Dechant and West 1985; Erman et al. 1988). We believe that such effects were not observed in the South Branch because stream flows during spawning and incubation (primarily October-March) were not high enough to significantly damage brown trout redds.

Winter severity, as characterized by either the frequency of severe cold (air temperatures) or cooling degree days had no detectable effect on brown trout recruitment. Some investigators have reported adverse effects of anchor ice, and ice scouring on salmonid reproductive success (Nelson 1984; Dechant and West 1985). Over the years we have seen anchor, shelf, frazil, and surface ice on the South Branch. Virtually all trout streams in northern Michigan have such ice formations at some time during the winter. We assumed our measures of winter severity would be proportional to the amount of ice formation. If this assumption was correct and icing was more severe during colder winters, then whatever effect ice had on reproduction was insignificant compared to the effects of high stream flows in April and May.

Implications

Our findings showed that high spring flows can have significant adverse effects on recruitment of young brown trout even in a relatively stable flowing stream. Nearly all forms of land development increase the amount of surface runoff into streams, but those impacts should be minimized whenever possible. For example, running ditches and storm sewers directly into streams should be avoided. Upland management to trap more water in retention basins (groundwater recharge basins) should reduce peaks in runoff and should be encouraged. In Michigan, rapid drawdowns of lakes during spring to prevent flooding of lake front properties is a widespread practice which increases the flow in streams below. This practice is likely to cause adverse effects on brown trout recruitment in those streams. The converse is probably true, also. If high lake levels were not a problem, it might be possible to enhance brown trout recruitment by using such reservoirs to store, and then, gradually release spring runoff. In the specific case of the South Branch of the Au Sable River, we should continue to advocate responsible operation of the lake level control structure below Lake St. Helen.

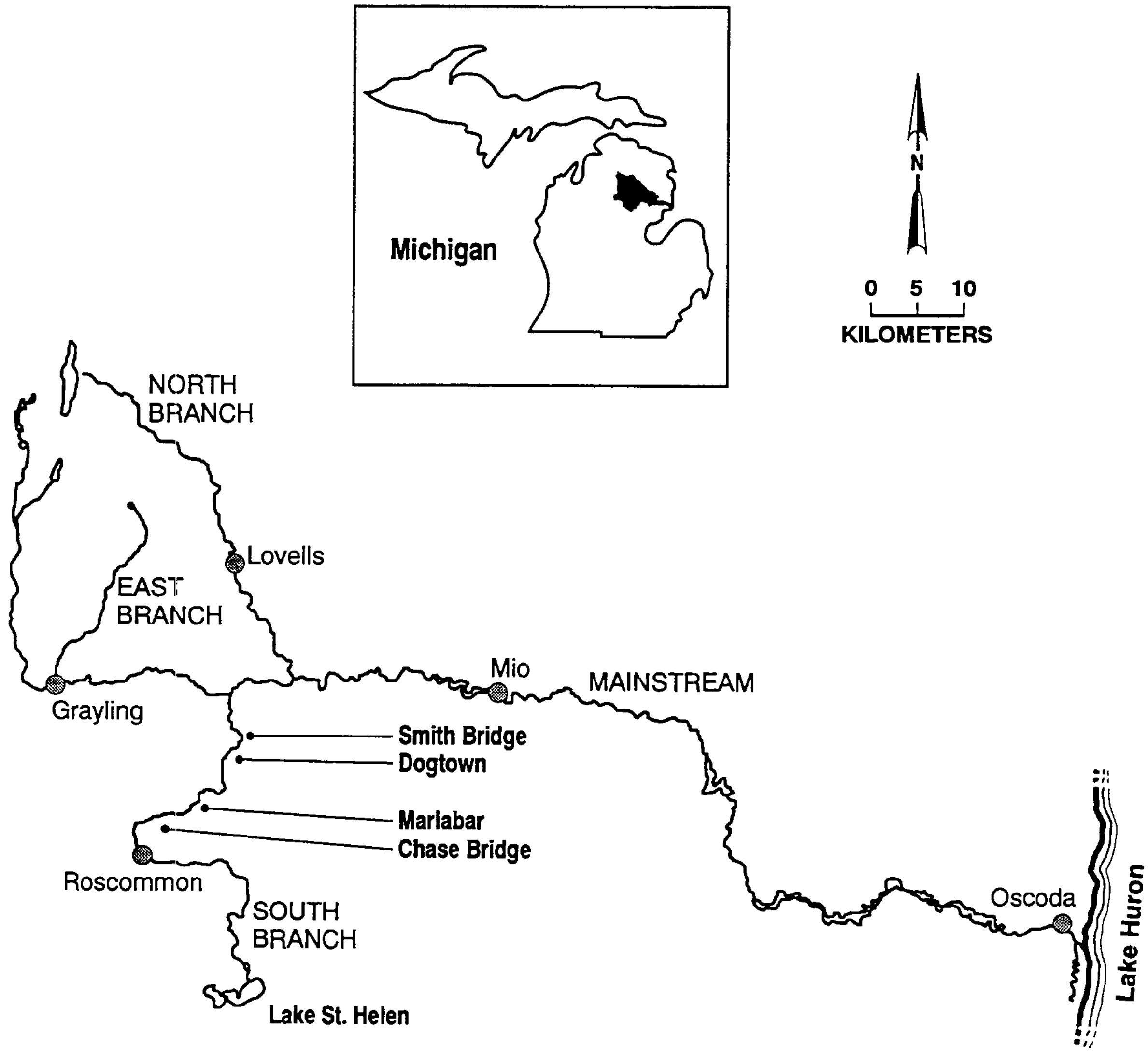

Figure 1.—Map of the major branches of the Au Sable River system showing trout population sampling areas for the South Branch. Inset shows the location of the Au Sable River watershed within Michigan's Lower Peninsula.

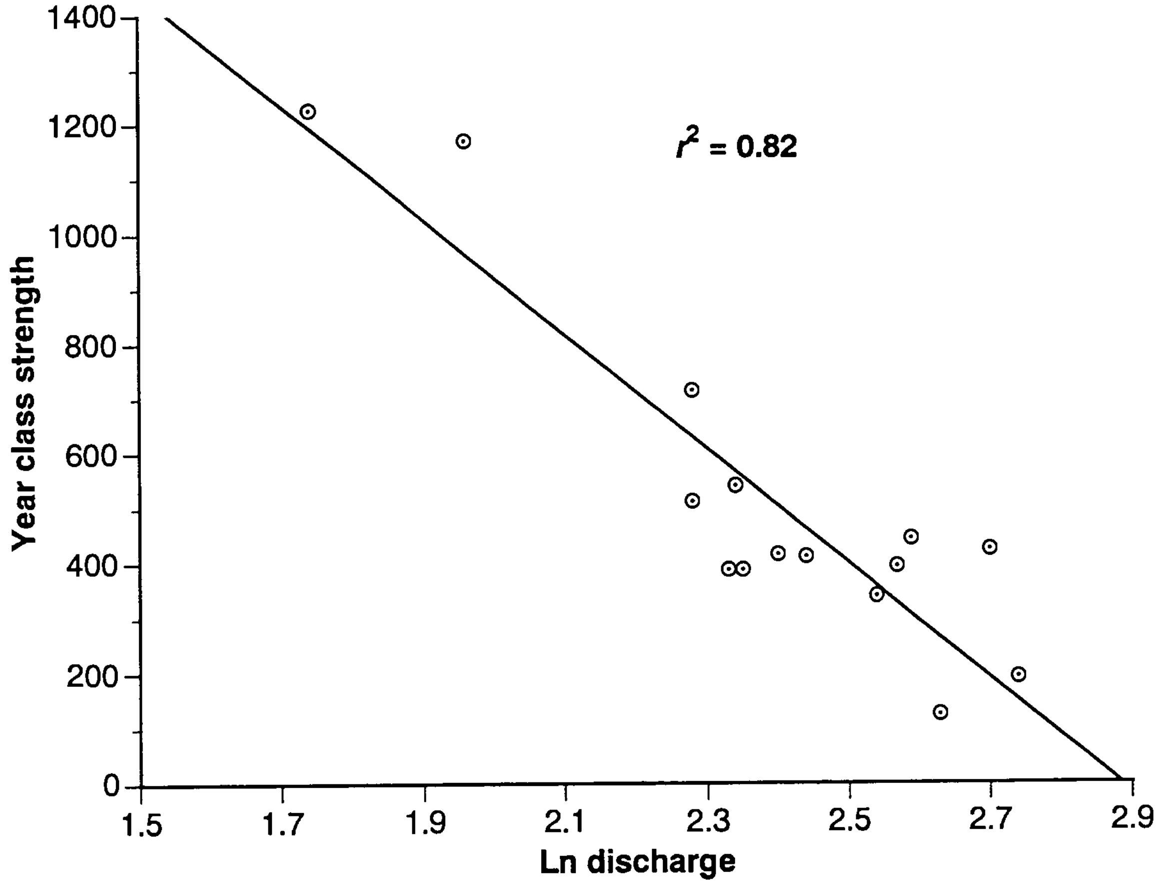

Figure 2.—Relationship between year class strength (fall numbers of age 0 brown trout per hectare) and natural log of mean daily discharge (m^3/s) from 6 April through 5 May at Smith Bridge.

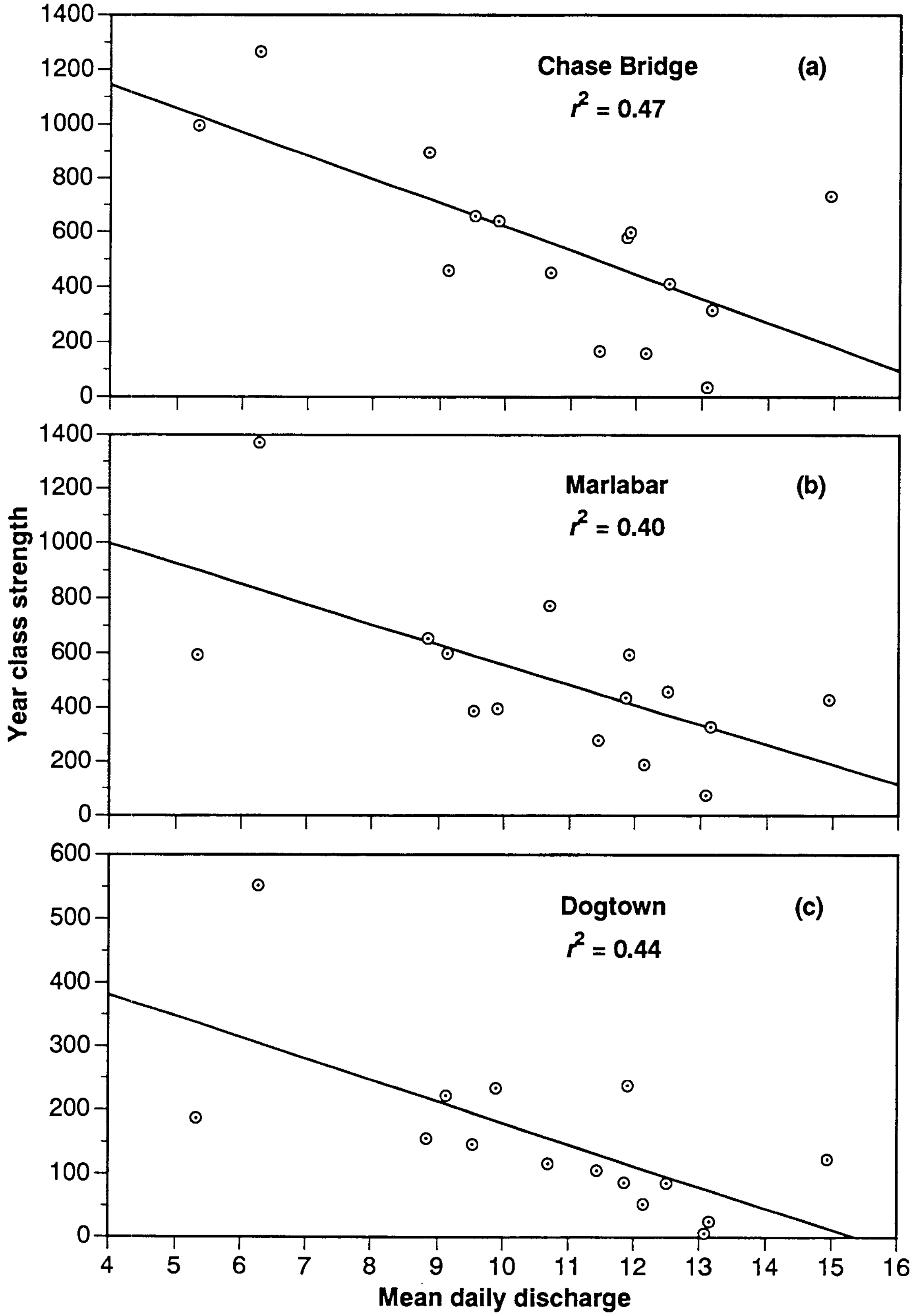

Figure 3.—Relationship between year class strength (fall numbers of age 0 brown trout per hectare) at 3 stations and mean daily discharge (m^3/s) from 13 April through 12 May.

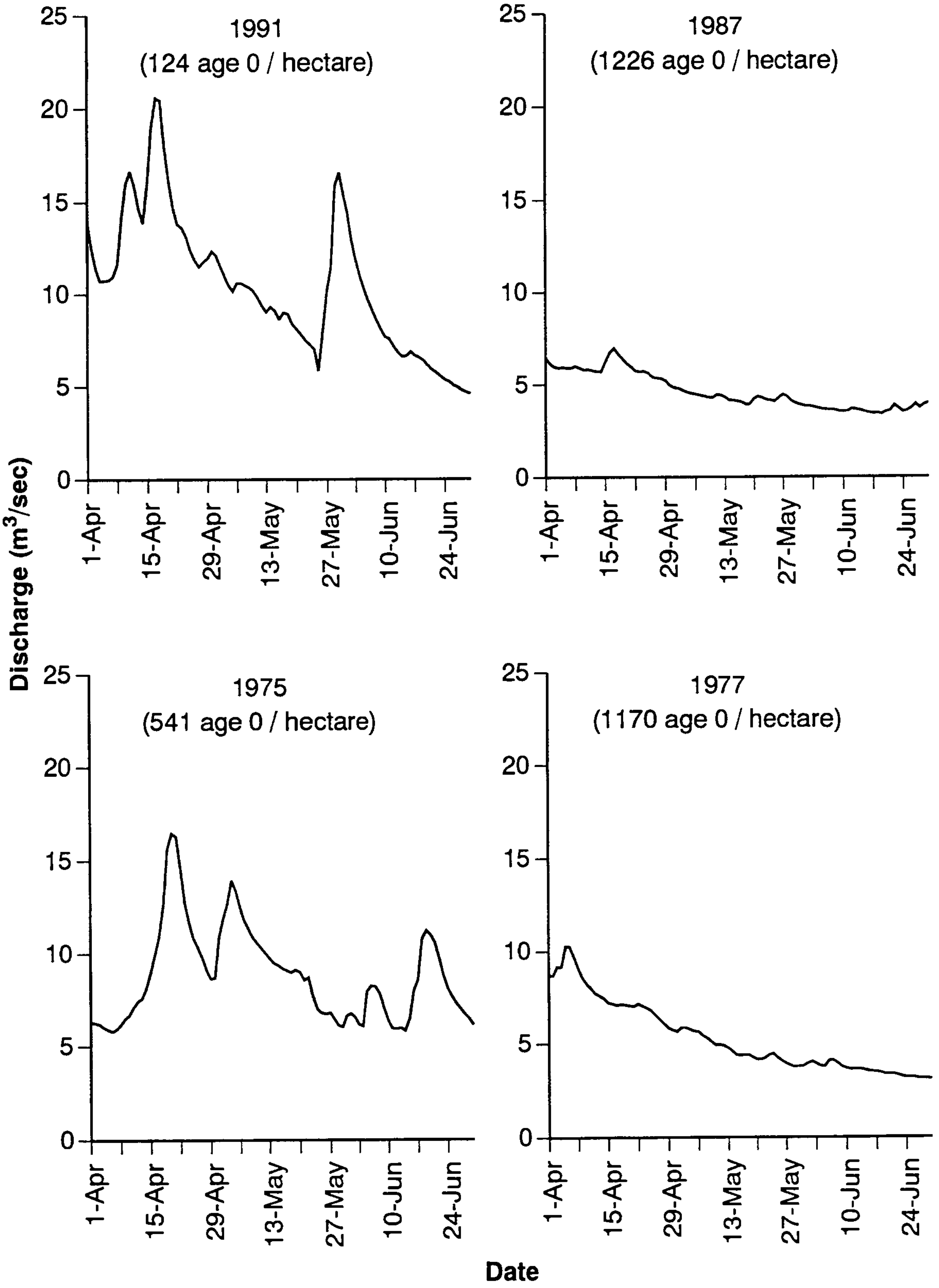

Figure 4.—Mean daily discharge of the South Branch Au Sable River at Smith Bridge from 1 April through 30 June for selected years with corresponding numbers of age 0 brown trout per hectare the following fall.

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James S. Diana, Editor
Barbara A. Diana, Word Processor
Alan D. Sutton, Graphics
Kathryn L. Champagne, DTP

Appendix 1. Variables tested for correlations with brown trout year class strength. Only representative samples of variables that are part of a logical time series are shown.

Monthly stream discharge variables

Mean daily discharge for individual months from October - September.
Minimum daily discharge for individual months from October - September.
Maximum daily discharge for individual months from October - September.

Stream discharge for 30-day intervals during the late incubation/emergence period

Mean daily discharge from 1 April - 30 April.
Mean daily discharge from 6 April - 5 May.
Mean daily discharge from 11 April - 10 May
  and so on by 5-day increments to the interval from 1 June - 30 June.

Stream discharge for 20-day intervals during the late incubation/emergence period

Mean daily discharge from 1 April - 20 April.
Mean daily discharge from 6 April - 25 April.
Mean daily discharge from 11 April - 30 April
  and so on by 5-day increments to the interval from 11 June - 30 June.

Stream discharge for 15-day intervals during the late incubation/emergence period

Mean daily discharge from 1 April - 15 April.
Mean daily discharge from 6 April - 20 April.
Mean daily discharge from 11 April - 25 April
  and so on by 5-day increments to the interval from 1 June - 30 June.

Miscellaneous discharge variables

Highest 7-day discharge occurring between 1 April and 30 May.
Highest daily discharge occurring between 1 April and 30 May.
Mean daily discharge from October - December.
Mean daily discharge from November - January.
Mean daily discharge from December - February.
Mean daily discharge from December - March.
Mean daily discharge from December - April.
Mean daily discharge from December - May.
Mean daily discharge from January - March.
Mean daily discharge from February - April.
Mean daily discharge from March - May.
Mean daily discharge from April - June.
Mean daily discharge from May - July.
Mean daily discharge from June - August.

Appendix 1. (Cont.)

Miscellaneous discharge variables

Mean daily discharge from July - September.

Stream discharge for 20-day intervals within the expected spawning season

Mean daily discharge from 16 September - 5 October.
Mean daily discharge from 21 September - 10 October.
Mean daily discharge from 26 September - 15 October
and so on by 5-day increments to the interval from 25 November - 14 December.

Frequency of occurrence of minimum air temperatures ≤ -10 C, ≤ -20 C, ≤ -25 C, or ≤ -30 C

Frequency during December.
Frequency during January.
Frequency during February.
Frequency during March.
Frequency from December - March.
Frequency from January - March.

Cooling degree days based on mean daily base air temperatures of 0 C, -10 C, or -15 C

Degree days during December.
Degree days during January.
Degree days during February.
Degree days during March.
Degree days during December - February.
Degree days during December - March.