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DFO Atlantic Fisheries
Research Document 93/26

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MPO Document de recherche sur
les pêches dans l'Atlantique
93/26

JUVENILE ATLANTIC SALMON (SALMO SALAR) DENSITIES AND EGG DEPOSITION IN THE RESTIGOUCHE AND MIRAMICHI RIVERS, NEW BRUNSWICK

by

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ABSTRACT

Two decades of electrofishing data from the Restigouche and Miramichi rivers were used to investigate the relationship between juvenile salmon abundance, egg deposition and site-dependent physical and biological factors. Juvenile salmon abundance was significantly related to egg deposition as well as to site-dependent cofactors (tributary, elevation, gradient, stream order, Julian date, effect of age 0+ recruitment on age 1+ abundance, effect of age 1+ presence on age 0+ abundance).

Percent Habitat Saturation (PHS: Grant and Kramer 1990) rarely exceeded 27%, supporting previous suggestions that both rivers could produce additional juvenile salmon in the available habitat.

RÉSUMÉ

On a utilisé des données d'électropêche recueillies pendant deux décennies dans les rivières Restigouche et Miramichi pour étudier les liens existant entre l'abondance du saumon juvénile, la ponte et des facteurs physiques et biologiques reliés au site. On a pu établir un lien net entre l'abondance des juvéniles et la ponte ainsi que les facteurs propres au site (tributaire, élévation, gradient, catégorie de cours d'eau, quantième de l'année, effet du recrutement à l'âge 0+ sur l'abondance du poisson d'âge 1+ et effet de la présence de poisson d'âge 1+ sur l'abondance du poisson d'âge 0+).

Le pourcentage de saturation de l'habitat (Grant et Kramer 1990) dépasse rarement 27 %, ce qui confirme les hypothèses antérieures selon lesquelles les deux rivières pourraient produire plus de saumon juvénile dans l'habitat restant.

INTRODUCTION

Information on egg deposition and juvenile salmon abundances has been collected from the Miramichi and Restigouche Rivers for the past two decades. During this time spawning levels and juvenile salmon densities have fluctuated considerably. Our objective in this paper is to utilize these data in order to address the following questions:

1 - Is there a functional relationship between egg deposition and juvenile abundance? What other site-related factors mediate this relationship?

2 - How has habitat utilization changed with increases in egg deposition?

3 - How do the two rivers compare with each other in terms of functional relationship and habitat utilization?

METHODS

EGG DEPOSITION:

Annual egg deposition rates were obtained for each river based on CAFSAC Assessment estimates (e.g. Courtenay et al. 1992, Moore et al. 1992). Egg deposition was expressed as number of eggs m^{-2} of suitable habitat.

JUVENILE ABUNDANCE:

Juvenile salmon abundance was determined by electrofishing surveys of 15 standard sites on each of two rivers (Restigouche River (Fig. 1), 1972-1991; Miramichi River (Fig. 2), 1970-1992). As described by Randall and Chadwick (1986), sites for electrofishing surveys were selected in areas of typical juvenile salmon habitat: flowing water averaging 10-50 cm deep, with varying proportions of cobble-boulder substrate. In both rivers, sites averaged about 300 m^2 in area (140-870 m^2) and were located in stream orders (Strahler 1957) 2 to 7. Electrofishing commenced in late June and continued until September, but most sites were surveyed in July and August. Water temperature during the surveys was between 8 and 27 C. Species commonly captured include Atlantic salmon, blacknose dace (Rhinichthys atratulus), slimy sculpin (Cottus cognatus) and brook trout (Salvelinus fontinalis).

Sites to be electrofished were surrounded by barrier nets (0.3 cm mesh) at the upstream and downstream extremities of each site. At higher stream order sites, where river width exceeded the length of the nets, a third barrier net was erected parallel to the shore. The enclosed sites were electrofished from the upstream to the downstream nets from 4 to 6 times. After each fishing sweep, captured fish were identified and counted. Salmon fork length was measured to the nearest 0.5 cm. After the last sweep, all fish were released back into the site.

Juvenile salmon were divided into fry, small parr and large parr categories on the basis of modes in length-frequency distribution. Ageing of scale samples collected in 1982 and 1983 indicated 100% of fry were age 0+, more than 90% of small parr were age 1+ and more than 80% of large parr were age 2+. Juvenile salmon in both rivers smoltify predominantly at ages 2 and 3 and age 3+ parr were rare. For the purpose of this study, fry, small parr and large parr were designated as 0+, 1+ and 2+ fish, respectively. Densities of each age-group were estimated separately by the removal method (Zippin 1956).

FACTORS DETERMINING JUVENILE ABUNDANCE:

We assumed that juvenile abundance was initially dependent on egg deposition and then added covariables which might explain site-to-site variability in juvenile abundance. Multiple regression models were constructed using abundance of 0+ or 1+ juveniles as the dependent variable, and egg abundance, elevation, grade, stream order, tributary and Julian date of sampling as independent variables. Analyses were conducted separately for the Restigouche and Miramichi data, as follows:

- Restigouche: Abundance of 0+ at each site in the previous year was used as an additional independent variable for models of 1+ abundance, and abundance of 1+ at each site in the current year was used as an additional independent variable for models of 0+ abundance. In these models, stream order and tributary were used as categorical variables and all other variables were continuous.

- Miramichi: In the 1+ parr model, 0+ densities of the same cohort were not used as a covariate. In the 0+ fry model, the covariate corresponding to parr density summed the abundance of 1+ and 2+ parr. Gradients and elevations were treated as categorical variables (gradient: 1-4, 5-9, 10-19, 20-29, 30-39, and ≥40 m/km; elevation: <50, 50-99, 100-149, 150-199, 200-249, 250-299, and ≥300m).

To determine the most suitable regression model for each of the two dependent variables, all possible regressions were computed with egg abundance included as a variable in all models. The resultant R^2 values were plotted as R^2 vs. number of independent variables. The combination of variables yielding the asymptotically highest R^2 was selected as the best regression model. For the Restigouche River data, this procedure was carried out using both log-transformed and untransformed variables. Since the log-transformed models provided a consistently better fit to the data, only these will be discussed here. Some quadratic models were also inspected, but R^2 values were lower than those of the log-log models. For the Miramichi River data, only log-transformed variables were analysed.

HABITAT SATURATION AND DENSITY DEPENDENT EFFECTS:

The Percent Habitat Saturation Index (PHS) of Grant and Kramer (1990) was calculated in order to assess changes in habitat utilization by juvenile salmon on a site-by-year basis. PHS integrates the number, size and space requirements of salmonids.

$$PHS = 100*\Sigma_i D_i * T_i * 1.19$$

where D_i = density (number m^{-2}) of size group i

T_i = territory size of individuals in size group i from territory size-body size regression ($\log_{10} T_i = 2.61 \log_{10}$ (body length) $- 2.83$; Grant and Kramer 1990)

The value 1.19 is a correction factor to remove bias introduced by the log-transformation of territory size and body length (Grant and Kramer 1990).

The PHS index can be used as an indicator of potential density-dependent effects on growth, mortality or emigration. The probability of a density-dependent response increases at PHS > 27%, according to a linear logistic response model with 81% accuracy of predicting such responses (Grant and Kramer 1990).

We also attempted to identify density-dependent effects on growth by examining mean body length of juveniles in each site in relation to juvenile abundance. Since juveniles grow throughout the summer, the Julian date on which the site was sampled also had to be included in this analysis. Log-transformed mean body length was therefore regressed on mean abundance and Julian date of sampling. This analysis was carried out separately for each of the 0+ and 1+ age categories.

RESULTS AND DISCUSSION

FACTORS DETERMINING JUVENILE ABUNDANCE:

Fry (age 0+)

In both rivers, there was a trend for egg deposition in excess of 2.4 eggs m^{-2} to result in increased numbers of electrofishing sites with high densities of 0+ fry (Fig. 3).

Regression analysis of fry abundance on egg abundance in the Restigouche River fit poorly (but significantly) with an R^2 of 0.077 (Table 1). A regression model involving four independent variables - egg abundance, stream order, tributary and Julian date - was selected as giving the best fit ($R^2 = 0.407$; Table 1). R^2 did not increase appreciably in models with additional independent variables. All four variables were significant at $p<0.004$ and the overall model was significant at $p=0.001$ (Table 2). Fry abundance increased with increasing egg deposition ($b=0.664$) and Julian date ($b=0.009$). Fry abundance was higher at sites of stream order 6 than sites of stream order 5 and 7. Fry abundance was lowest in stream order 4. Fry abundance was higher in the Main Restigouche and Kedgwick Rivers than in the Little Main Restigouche River. Residuals showed a trend associated with the inclusion of sites with zero abundance (Table 2).

In the Miramichi River data, inclusion of tributary, stream order, and density of older juveniles (1+ and 2+ parr) as covariates in the juvenile abundance - egg deposition model improved R^2 from 0.114 to 0.537 (Table 3). Inclusion of additional covariates - Julian date of sampling, stream gradient and elevation - did not greatly improve the correlation (R^2=0.544; Table 3). Fry densities at sites in the Southwest Miramichi were significantly higher than those in the Northwest, Little Southwest, and Main Miramichi sites (Table 4). Densities in the Little Southwest were significantly greater than those in the Main Miramichi, but not those in the Northwest Miramichi. Stream orders 3, 4, 5 and 6 were not significantly different in density of fry, and were all significantly greater than stream order 2, which was represented by only one site (#46) located in the Little Southwest Miramichi. Unexpectedly, the relationship between fry densities and parr densities was positive (b=0.301). We included parr density in the model because we hypothesized that a high number of parr might outcompete and exclude fry. Instead, it appears that where you find high parr densities, you also find high fry densities. A plot of residual versus predicted values reveals a trend in residuals resulting from inclusion of electrofishing samples with zero fry density (Figure 7).

Parr (age 1+)

High parr densities were more common at higher egg deposition rates (Table 4) although this trend was less pronounced for parr than for fry (Fig. 3).

In the Restigouche River, egg deposition alone was a less reliable predictor of 1+ parr abundance than of fry abundance; R^2 of the regression was only 0.019 (Table 5). The same four-variable model was selected for 1+ abundance as for 0+ abundance. In the case of 1+ abundance, this was not the overall best-fit model although it was the best of the 4-variable models, with an R^2 of 0.450 (Table 5). Two different five-variable models had higher R^2 than the 4-variable model. R^2 continued to improve through the 6-variable model. It was decided to use the four-variable model for simplicity since the six-variable model was not substantially better (R^2 = 0.486). The four-variable model showed that 1+ parr abundance increased with increasing egg deposition (b=0.238) and Julian date (b=0.005). Parr abundance was higher in stream order 7 sites than in any of the other stream orders. As was observed for for fry, parr were more abundant in the Main Restigouche and Kedgwick Rivers than in the Little Main Restigouche River (Table 6). Residuals showed the same trend due to inclusion of zero abundances as was seen for the fry regression analysis (Table 2).

In the Miramichi River dataset, including the covariates stream order, tributary, elevation, and gradient improved the regression of parr abundance on egg deposition from $R^2 = 0.068$ to $R^2 = 0.520$ (Table 7). Significantly fewer parr were found in stream order 6 than in the reference category, stream order 5. No other significant differences with stream order were detected (Table 8). Parr were significantly more abundant in the Main and Southwest Miramichi rivers than in the Northwest and Little Southwest (a tributary of the Northwest Miramichi) rivers (Table 8). This contrasts with the lower fry densities in the Main Miramichi relative to the Southwest and Little Southwest Miramichi rivers (Table 4). Sites at elevations <100 m held significantly lower parr densities than sites at 150m or above (Table 8). Only three of the 15 standard electrofishing sites are above 100m (#46, #60, and #92; Fig. 2). Sites of lower gradient (i.e., < 10m/km) showed significantly lower parr densities than sites of higher gradient (>10 m/km) (Table 8). All sites had a gradient < 10m/km except for two of the three sites on the Little Southwest Miramichi River. A plot of residuals versus predicteds reveals a trend in the data consequent of inclusion of zero parr densities (Table 4).

General comments

The inadequacy of egg deposition alone to explain abundance of juveniles on a site-by-site basis is not a new conclusion; Randall and Chadwick (1986) found that summing total numbers of individuals over all sites improved the relationship with egg deposition and concluded that average density balanced out the effects of juveniles moving in and out of sites. We similarly obtained higher R^2 values with average density regressed on egg deposition (unpublished data) than with site-by-site density regressed on egg deposition. However, movement of juveniles between sites probably does not account for the poor fit obtained with site-by-site data. Mark-recapture studies (Randall and Paim 1982) show that little parr movement occurs from July to September during our annual electrofishing survey. The main movement of parr occurs in October (Randall and Paim 1982). Thus movement is not an adequate explanation, except for age 2+ individuals which might have moved in the previous October. At least two other possibilities exist. The first of these is that the estimates of egg deposition (although the best available) may be inaccurate. In both rivers, egg deposition is estimated using calculated spawner escapement, and biological data specific to salmon from each river (sex ratio, eggs/kg of fish, and mean fish size). Spawner escapement is calculated using different methodologies (see Courtenay et al. 1992 and Moore et al. 1992 for details) in the two rivers, and is considered to be more closely approximated in the Miramichi than in the Restigouche. Even so, the R^2 values observed for regression of site-by-site abundance on egg abundance in the Miramichi River are not much higher than those obtained with Restigouche data (for age 0+, 0.114 in the Miramichi, 0.077 in the Restigouche; for age 1+, 0.068 in the Miramichi, 0.019 in the Restigouche; Tables 1-4). A second problem is that even if egg deposition is estimated accurately, it is determined for the river as a whole and does not take into account population- or spawning site-dependent differences between and within tributaries. The improved relationship obtained when tributary and stream order (significant in all four models; Tables 1-4) are incorporated as explanatory variables suggests that treating the entire watershed as one spawning unit is an oversimplication. Stream order and tributary are variables which are to some extent confounded. In the 15 Restigouche River sites used for this analysis, for example, sites of stream order 7 are found only in the Main Restigouche River. However, analysis of a larger dataset (55 sites, not sampled every year) supports the conclusions presented here.

In the case of the Miramichi River, one important result of this analysis is that, for management purposes, the Southwest Miramichi tributary must be considered separately from the rest of the river. Fry densities are both larger and more variable between years in the Southwest Miramichi River than elsewhere. For the nine sites in the Southwest, the mean density (years pooled within site) is 62.4 fry/100 m^2, and the mean standard deviation is 49.8. In comparison, the mean density is 16.9 fry/100 m^2 and mean standard deviation is 19.4 in the 6 sites located in the Northwest, Little Southwest, and Main Miramichi. Parr are also more numerous in the Southwest than elsewhere (mean 11.8 parr/100 m^2 compared with 7.0 parr/100 m^2 in other tributaries) but the interannual variation at sites is comparable (average standard deviation: 8.0 cf 6.7). The lower interannual variation in parr densities than fry densities may reflect redistribution of juveniles in the system during their first year of life, or density dependent mortality.

HABITAT SATURATION AND DENSITY-DEPENDENT EFFECTS:

Percent Habitat Saturation

In both rivers, high PHS values have been more common in recent years (Figs. 9, 10). Mean PHS values were lower in the Restigouche in the 1970's than in the Miramichi (Figs. 11, 12) but since the mid-1980s, the two systems have had similar mean PHS values of approximately 14%. PHS values in excess of 27% at individual sites have been estimated in all but three years in the Miramichi River, but only in six years (primarily since 1987) in the Restigouche (Figs. 11, 12).

Both systems have low PHS values compared to the 27% level at which density-dependent effects are likely (Kramer and Grant 1990). This suggests that both systems have the capacity to support larger numbers of juveniles. Randall and Chadwick (1986) reached a similar conclusion based on estimates of production of juveniles in the two rivers. Density of juveniles was directly correlated to production, thus they concluded that juvenile salmon populations were below carrying capacity. Elson (1967) suggested that small parr levels of about 24 100 m^{-2} are required for optimum smolt yields on the Miramichi River; this level of abundance of small parr was not routinely achieved on either the Miramichi or Restigouche (Table

4).

In the Margaree River, PHS values have regularly exceeded 30% over the time series from 1976 to 1992. Mean values for five sites in the Margaree have ranged between 30 and 40% since 1987 (Chaput et al. 1992). Densities of fry have averaged from 16 to 140 per unit of area while average parr densities (small and large combined) have ranged between 19 and 58 for the period 1957 to 1987 (Chaput and Claytor 1989). The number of spawners generating the maximum number of juveniles may not be the level which results in maximum recruitment of adults as shown for Western Arm Brook (Chaput et al. WP 1992).

Density Dependent Effects on Size

Both fry abundance and Julian date significantly affected length of fry in the Restigouche sites ($R^2 = 0.427$). Mean length of fry decreased with increasing abundance ($b = -0.017$) and increased with Julian date ($b = 0.003$). Both slopes were significant at $p < 0.05$.

No significant effect of abundance on length was observed for Restigouche parr or for Miramichi fry or parr.

Thus an inverse relationship between abundance and body length is only weakly supported. Such a relationship might be indicative of a density-dependent relationship such as competition, especially for the fry which are less mobile than parr. However, there is a confounding effect between the two independent variables in the model which weakens the utility of this analysis. As expected, both fry and parr grow larger throughout the summer, justifying the inclusion of Julian date as a covariable. There is also a positive relationship between juvenile abundance and Julian date; thus the 'independent variables' are not truly independent.

CONCLUSIONS

1. In both rivers, there was a significant relationship between both eggs and fry and eggs and parr. This relationship is improved by addition of covariates describing the habitat.

2. In both rivers, there were important differences in juvenile abundances in different tributaries.

3. In both rivers, average habitat saturation falls below 27%, the level above which density-dependent effects might be observed (Grant and Kramer 1990). Thus there appears to be room for additional production of juveniles.

4. Even in years when the egg deposition target of 2.4 eggs m^{-2} was exceeded, juvenile habitat was apparently not fully saturated.

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Table 1. Best-fit models for the regression of log-transformed egg abundance and selected physical characteristics of electrofishing sites on log-transformed 0+ densities (Restigouche River).

No. of independent variables	Independent variables in the best-fit model	R^2
1	Egg	0.077
2	Egg, stream order	0.333
3	Egg, stream order, Julian date	0.389
4	Egg, stream order, Julian date, tributary	0.407
5	Egg, stream order, Julian date, tributary, grade	0.410
5	Egg, stream order, Julian date, grade, elevation	0.410
6	Egg, stream order, Julian date, tributary, grade, elevation	0.411
7	Egg, stream order, Julian date, tributary, grade, elevation, competition from 1+	0.406

Table 2. SAS output of regression of log (fry abundance) in Restigouche River electrofishing sites on log (egg deposition), with Julian date, stream order and tributary as covariates.

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The SAS System                                                                                                                   2
                                                                                                     14:35 Sunday, November 22, 1992

General Linear Models Procedure

Dependent Variable: DENSITY0

Source                DF        Sum of Squares         Mean Square       F Value          Pr > F

Model                  6           47.05474147          7.84245691         32.68          0.0001

Error                286           68.63763425          0.23999173

Corrected Total      292          115.69237572

                R-Square                  C.V.            Root MSE                 DENSITY0 Mean

                0.406723              44.54817          0.48988951                    1.09968492

Source                DF             Type I SS         Mean Square       F Value          Pr > F

EGG                    1            8.93088561          8.93088561         37.21          0.0001
JUL0                   1            7.24536154          7.24536154         30.19          0.0001
STRORD                 3           28.81923436          9.60641145         40.03          0.0001
TRIBUT                 1            2.05925997          2.05925997          8.58          0.0037

Source                DF           Type III SS         Mean Square       F Value          Pr > F

EGG                    1            6.13849210          6.13849210         25.58          0.0001
JUL0                   1            6.98525378          6.98525378         29.11          0.0001
STRORD                 2           21.79654624         10.89827312         45.41          0.0001
TRIBUT                 1            2.05925997          2.05925997          8.58          0.0037

                                                       T for H0:              Pr > |T|              Std Error of
Parameter                      Estimate              Parameter=0                                       Estimate

INTERCEPT                 -2.317041800 B                   -6.03                0.0001                0.38429515
EGG                        0.664416299                      5.06                0.0001                0.13137344
JUL0                       0.008989086                      5.40                0.0001                0.00166618
STRORD      5              0.544371225 B                    7.59                0.0001                0.07175185
            6              0.790433890 B                    8.63                0.0001                0.09156856
            7              0.462845590 B                    4.45                0.0001                0.10408263
            10             0.000000000 B                     .                   .                     .
TRIBUT      LMRR          -0.206744746 B                   -2.93                0.0037                0.07057925
            MRR            0.000000000 B                     .                   .                     .
            ZKR            0.000000000 B                     .                   .                     .

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations.   Estimates followed by the letter 'B' are
      biased, and are not unique estimators of the parameters.
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Table 3. Best-fit models for the regression of log-transformed egg abundance and selected physical characteristics of Miramichi electrofishing sites on log-transformed 0+ densities.

No. of independent variables	Independent variables in the best-fit model	R^2
1	Egg	0.114
2	Egg, tributary	0.410
3	Egg, tributary, stream order	0.498
4	Egg, tributary, stream order, parr density	0.537
5	Egg, tributary, stream order, parr density, Julian date	0.541
6	Egg, tributary, stream order, parr density, Julian date, gradient	0.544
7	Egg, tributary, stream order, parr density, Julian date, gradient, elevation	0.544

Table 4. SAS output of regression of log (fry abundance) in Miramichi River electrofishing sites on log (egg deposition), with stream order, tributary and log (1+ and 2+ parr abundance) as covariates.

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The SAS System                                                                                                        2
                                                                                               14:45 Sunday, November 22, 1992

General Linear Models Procedure

Dependent Variable: DENS0

Source                  DF            Sum of Squares           Mean Square        F Value         Pr > F

Model                    9               85.31259549            9.47917728          37.43         0.0001

Error                  291               73.69904780            0.25326133

Corrected Total        300              159.01164329

                  R-Square                      C.V.              Root MSE                     DENS0 Mean

                  0.536518                  38.57553            0.50325077                     1.30458561

Source                  DF                 Type I SS           Mean Square        F Value         Pr > F

EGGS                     1               18.05486895           18.05486895          71.29         0.0001
STRORD                   4               24.74477150            6.18619288          24.43         0.0001
TRIB                     3               36.31264666           12.10421555          47.79         0.0001
DENS2                    1                6.20030837            6.20030837          24.48         0.0001

Source                  DF               Type III SS           Mean Square        F Value         Pr > F

EGGS                     1               15.24067848           15.24067848          60.18         0.0001
STRORD                   4               14.16042514            3.54010628          13.98         0.0001
TRIB                     3               24.78519684            8.26173228          32.62         0.0001
DENS2                    1                6.20030837            6.20030837          24.48         0.0001

                                                              T for H0:               Pr > |T|                Std Error of
Parameter                            Estimate                Parameter=0                                        Estimate

INTERCEPT                         1.153130865 B                  11.43                  0.0001                  0.10089187
EGGS                              0.926415007                     7.76                  0.0001                  0.11942297
STRORD       2                   -1.004908490 B                  -6.99                  0.0001                  0.14378752
             3                   -0.028319515 B                  -0.21                  0.8305                  0.13218533
             4                   -0.133350122 B                  -1.52                  0.1284                  0.08746358
             6                   -0.150641624 B                  -1.37                  0.1708                  0.10971092
             ~~10~~ 5             0.000000000 B                    .                      .                       .
TRIB         LSWMR               -0.513375686 B                  -4.44                  0.0001                  0.11571389
             MMR                 -0.811571705 B                  -8.41                  0.0001                  0.09645684
             NWMR                -0.816476481 B                  -5.21                  0.0001                  0.15674034
             ZSWMR                0.000000000 B                    .                      .                       .
DENS2                             0.301118787                     4.95                  0.0001                  0.06085772

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations.   Estimates followed by the letter 'B' are
      biased, and are not unique estimators of the parameters.
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Table 5. Best-fit models for the regression of log-transformed egg abundance and selected physical characteristics of electrofishing sites on log-transformed 1+ densities (Restigouche River).

No. of independent variables	Independent variables in the best-fit model	R^2
1	Egg	0.019
2	Egg, tributary	0.385
3	Egg, tributary, Julian date	0.431
4	Egg, tributary, Julian date, stream order	0.450
5	Egg, tributary, Julian date, stream order, elevation	0.469
5	Egg, tributary, Julian date, stream order, density of 0+ in previous year	0.469
6	Egg, tributary, Julian date, stream order, elevation, grade	0.486
7	Egg, tributary, Julian date, stream order, elevation, grade, density of 0+ in previous year	0.487

Table 6. SAS output of regression of log (1+ parr abundance) in Restigouche River electrofishing sites on log (egg deposition), with Julian date, stream order and tributary as covariates.

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The SAS System                                                                                           2
                                                                               14:36 Sunday, November 22, 1992
General Linear Models Procedure

Dependent Variable: DENSITY1

Source                DF         Sum of Squares          Mean Square       F Value        Pr > F

Model                  6            24.11785458           4.01964243         37.00        0.0001

Error                271            29.44313590           0.10864626

Corrected Total      277            53.56099047

                R-Square                   C.V.             Root MSE                DENSITY1 Mean

                0.450288               48.03867           0.32961532                   0.68614583

Source                DF              Type I SS          Mean Square       F Value        Pr > F

EGG                    1             0.99937331           0.99937331          9.20        0.0027
JUL1                   1             3.27618028           3.27618028         30.15        0.0001
STRORD                 3             5.28833869           1.76277956         16.22        0.0001
TRIBUT                 1            14.55396230          14.55396230        133.96        0.0001

Source                DF            Type III SS          Mean Square       F Value        Pr > F

EGG                    1             0.79995820           0.79995820          7.36        0.0071
JUL1                   1             2.60828352           2.60828352         24.01        0.0001
STRORD                 2             1.02101981           0.51050990          4.70        0.0099
TRIBUT                 1            14.55396230          14.55396230        133.96        0.0001

                                                          T for H0:               Pr > |T|               Std Error of
Parameter                      Estimate                 Parameter=0                                       Estimate

INTERCEPT                 -.7459951366 B                     -2.74                 0.0066                 0.27237145
EGG                       0.2381746770                        2.71                 0.0071                 0.08777469
JUL1                      0.0054850710                        4.90                 0.0001                 0.00111947
STRORD      5             0.1165566155 B                      2.35                 0.0194                 0.04956769
            6             -.0410941782 B                     -0.65                 0.5164                 0.06325232
            7             0.1463410166 B                      2.04                 0.0422                 0.07167813
            10            0.0000000000 B                       .                     .                       .
TRIBUT      LMRR          -.5639885364 B                    -11.57                 0.0001                 0.04872895
            MRR           0.0000000000 B                       .                     .                       .
            ZKR           0.0000000000 B                       .                     .                       .

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations.   Estimates followed by the letter 'B' are
      biased, and are not unique estimators of the parameters.
```

Table 7. Best-fit models for the regression of log-transformed egg abundance and selected physical characteristics of Miramichi electrofishing sites on log-transformed 1+ densities.

No. of independent variables	Independent variables in the best-fit model	R^2
1	Egg	0.068
2	Egg, stream order	0.299
3	Egg, stream order, elevation	0.404
4	Egg, stream order, elevation, tributary	0.503
5	Egg, stream order, elevation, tributary, gradient	0.520
6	Egg, stream order, elevation, tributary, gradient, Julian date	0.521

Table 8. SAS output of regression of log (1+ parr abundance) in Miramichi River electrofishing sites on log (egg deposition), with stream order, tributary, elevation and gradient as covariates.

```
The SAS System                                                                                       2
                                                                         13:32 Sunday, November 22, 1992
General Linear Models Procedure

Dependent Variable: DENS10

Source                 DF         Sum of Squares         Mean Square       F Value        Pr > F

Model                  13            71.53786074          5.50291236         21.62        0.0001

Error                 260            66.16831241          0.25449351

Corrected Total       273           137.70617316

                 R-Square                   C.V.            Root MSE                  DENS10 Mean

                 0.519496               78.65978          0.50447350                   0.64133604

Source                 DF              Type I SS         Mean Square       F Value        Pr > F

EGGS                    1             9.12663190          9.12663190         35.86        0.0001
STRORD                  4            32.01700352          8.00425088         31.45        0.0001
TRIB                    3            12.42104836          4.14034945         16.27        0.0001
ELEV1                   3            15.71097663          5.23699221         20.58        0.0001
GRADE1                  2             2.26220033          1.13110017          4.44        0.0126

Source                 DF            Type III SS         Mean Square       F Value        Pr > F

EGGS                    1             8.75009160          8.75009160         34.38        0.0001
STRORD                  2            15.30262909          7.65131454         30.06        0.0001
TRIB                    2            13.50250421          6.75125210         26.53        0.0001
ELEV1                   2             7.49192644          3.74596322         14.72        0.0001
GRADE1                  2             2.26220033          1.13110017          4.44        0.0126

                                                           T for H0:             Pr > |T|             Std Error of
Parameter                         Estimate               Parameter=0                                    Estimate

INTERCEPT                      1.792360117 B                   6.67               0.0001               0.26870516
EGGS                           0.715049278                     5.86               0.0001               0.12194613
STRORD     2                  -0.199180633 B                  -0.88               0.3819               0.22741757
           3                  -0.047150227 B                  -0.17               0.8684               0.28433558
           4                   0.087979548 B                   0.73               0.4667               0.12070104
           6                  -1.133386562 B                  -4.13               0.0001               0.27421752
           ~~10~~ 5            0.000000000 B                    .                   .                     .
TRIB       LSWMR              -0.980395904 B                  -6.22               0.0001               0.15763876
           MMR                 0.116750073 B                   0.74               0.4596               0.15763876
           NWMR                0.221707377 B                   0.85               0.3970               0.26133340
           ZSWMR               0.000000000 B                    .                   .                     .
ELEV1      25                 -0.828781548 B                  -5.17               0.0001               0.16034463
           75                 -0.397446356 B                  -2.52               0.0123               0.15763876
           125                -0.156571504 B                  -0.48               0.6297               0.32433494
           175                 0.000000000 B                    .                   .                     .
           275                 0.000000000 B                    .                   .                     .
GRADE1     1                   0.000000000 B                    .                   .                     .
           5                  -0.606293860 B                  -2.93               0.0037               0.20699226
           10                 -0.727550928 B                  -2.47               0.0140               0.29419724
           20                  0.000000000 B                    .                   .                     .
           50                  0.000000000 B                    .                   .                     .

NOTE: The X'X matrix has been found to be singular and a generalized inverse was used to solve the normal equations.   Estimates followed by the letter 'B' are
      biased, and are not unique estimators of the parameters.
```

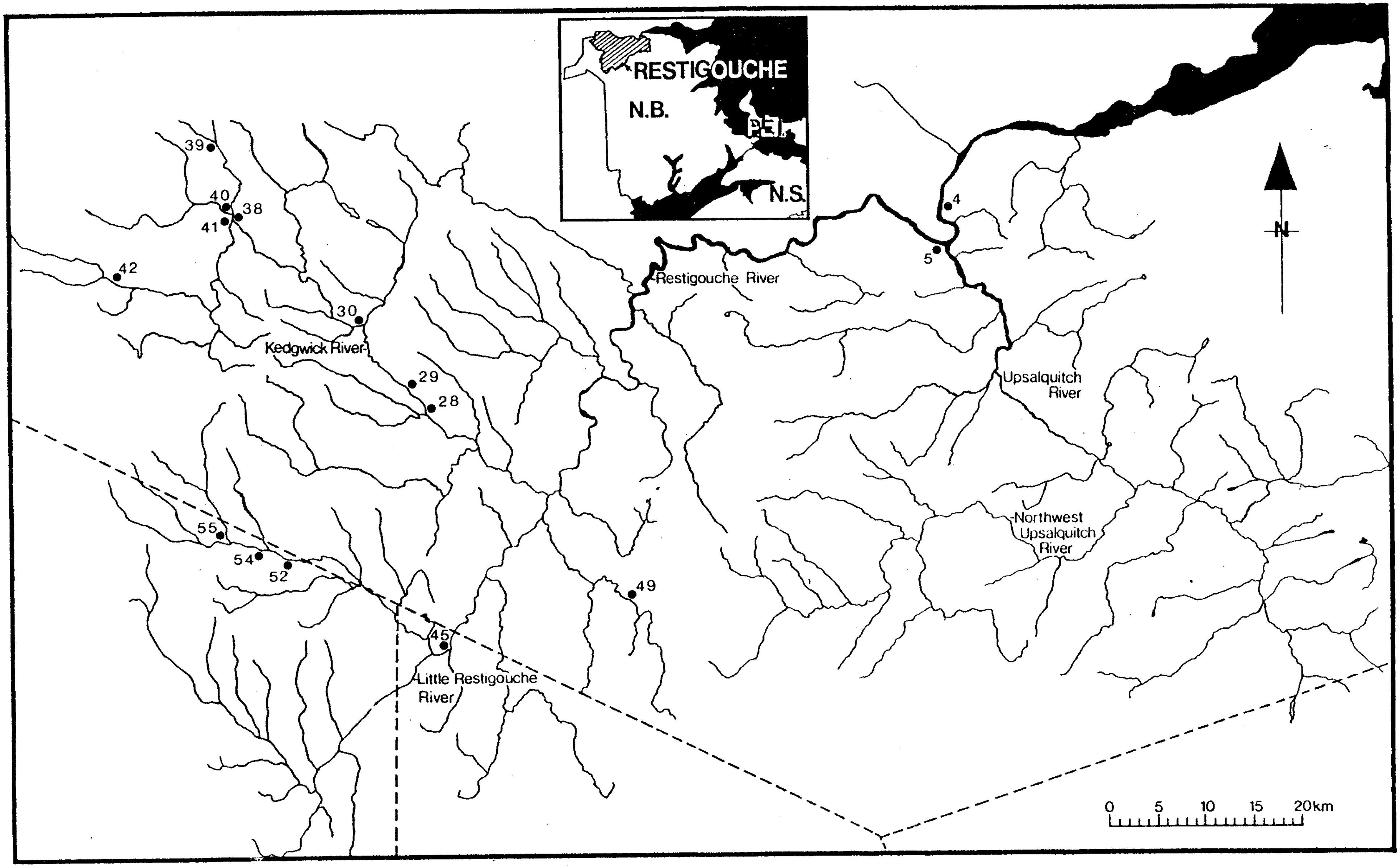


Figure 1. Map of the Restigouche River system showing location of electrofishing sites.

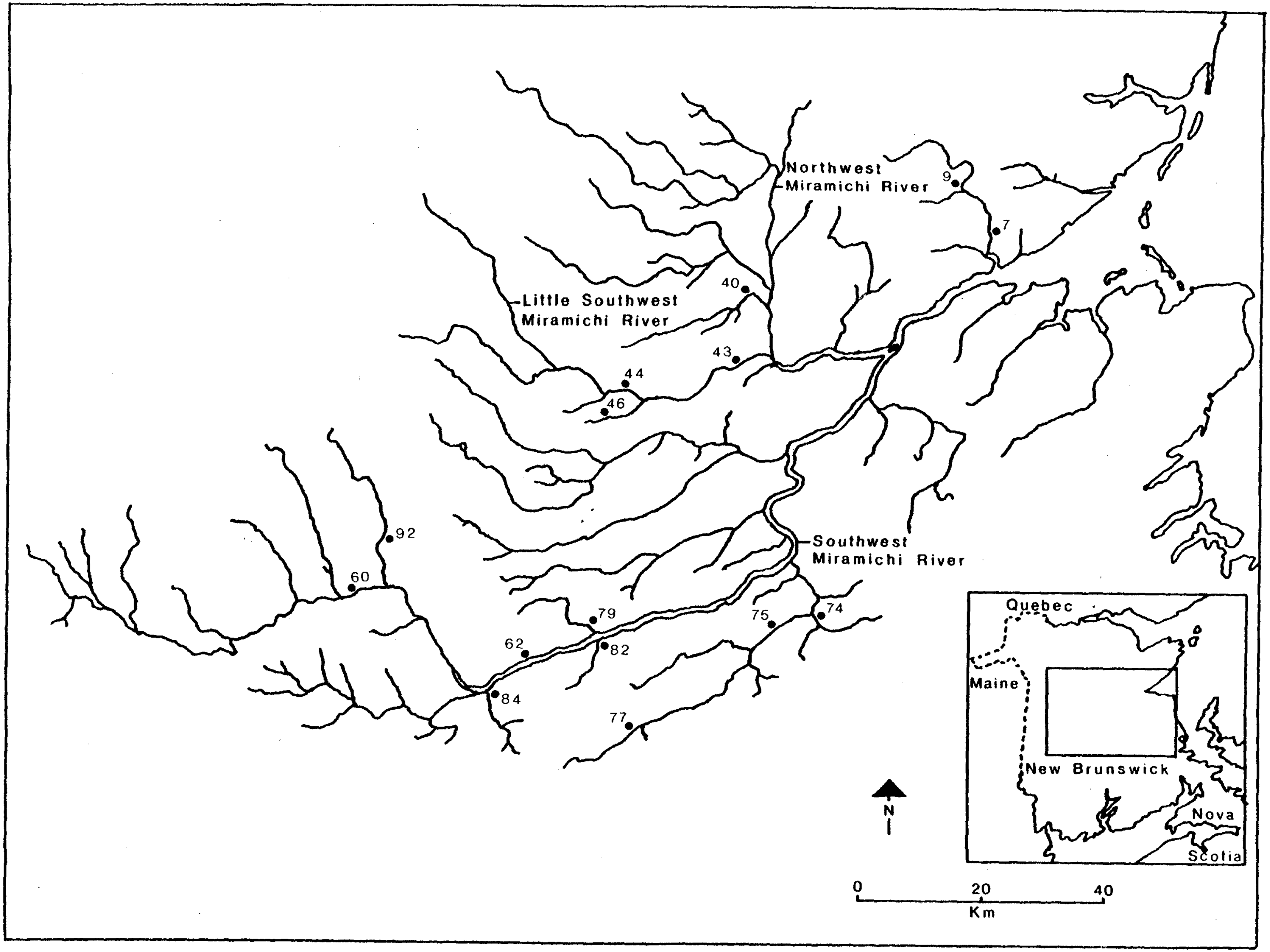


Figure 2. Map of the Miramichi River system showing location of electrofishing sites.

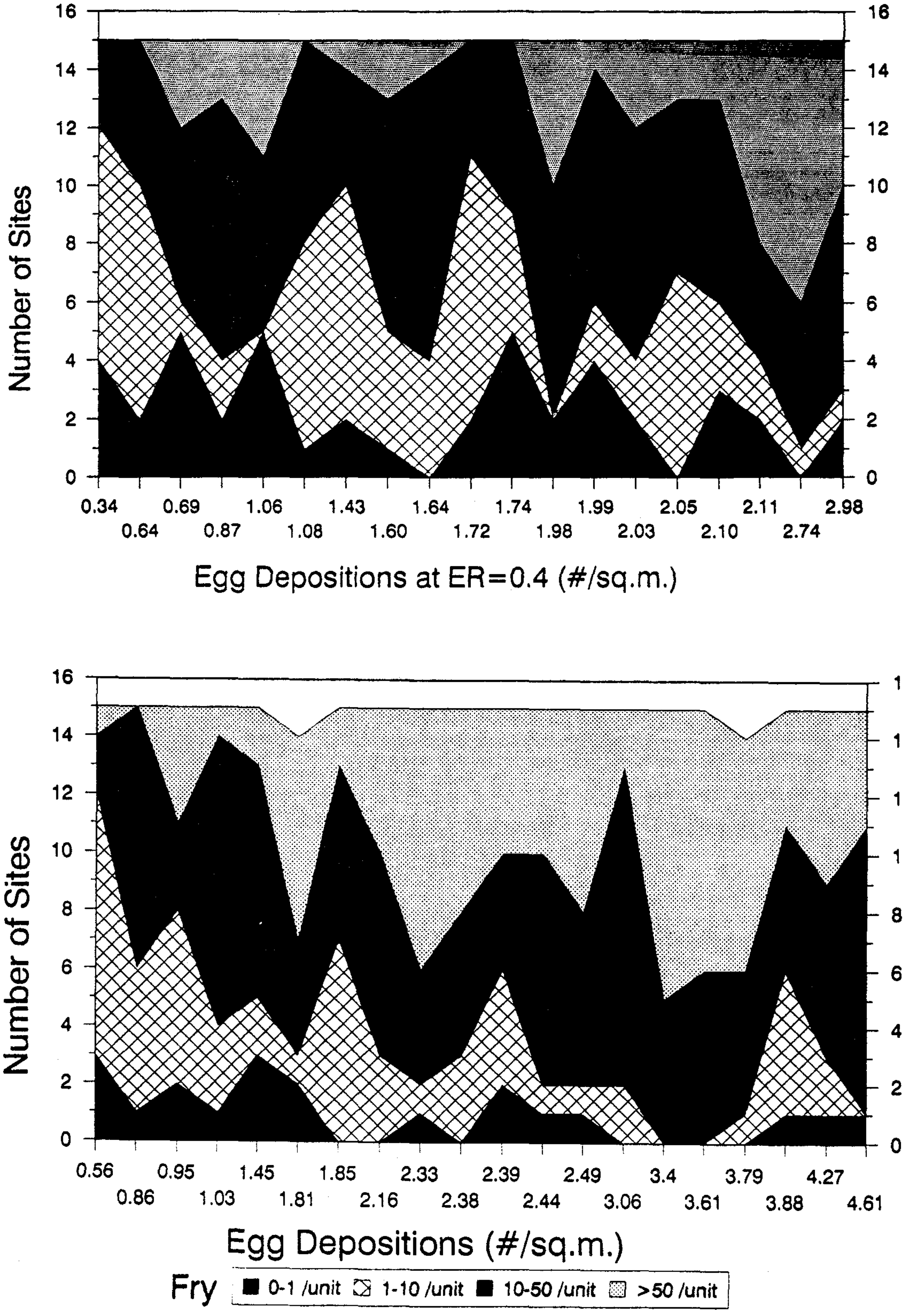
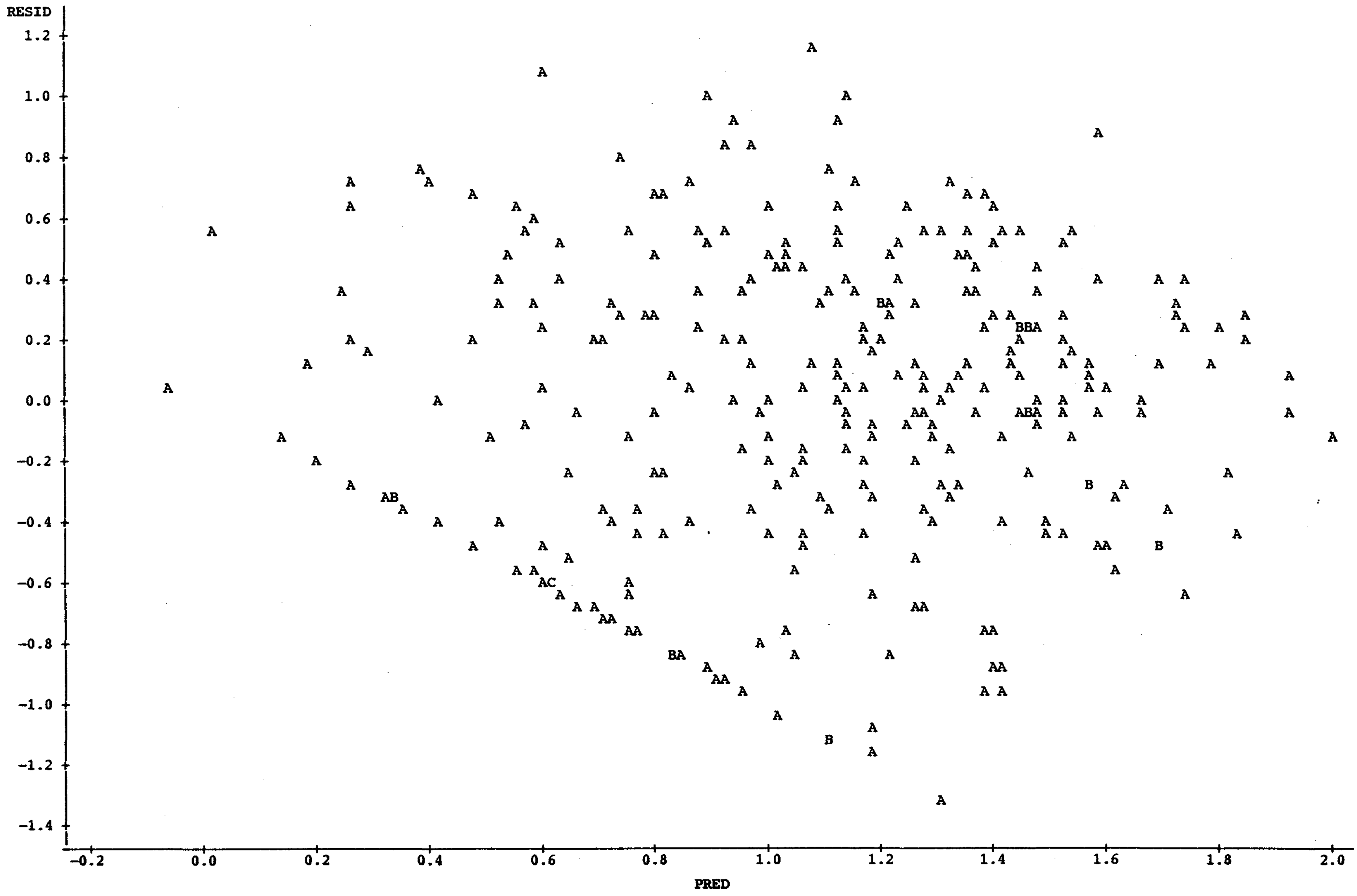


Figure 3. Fry abundances (no./m^2) in relation to egg deposition levels. (a) Restigouche River (egg depositions determined at angling exploitation rate (ER) = 0.4), (b) Miramichi River.

Plot of RESID*PRED. Legend: A = 1 obs, B = 2 obs, etc.



NOTE: 15 obs had missing values.

Figure 4. Residual vs. predicted values of log (fry abundance) in Restigouche River electrofishing sites regressed on log (egg deposition), with Julian date, stream order and tributary as covariates.

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Plot of RES*PRED. Legend: A = 1 obs, B = 2 obs, etc.

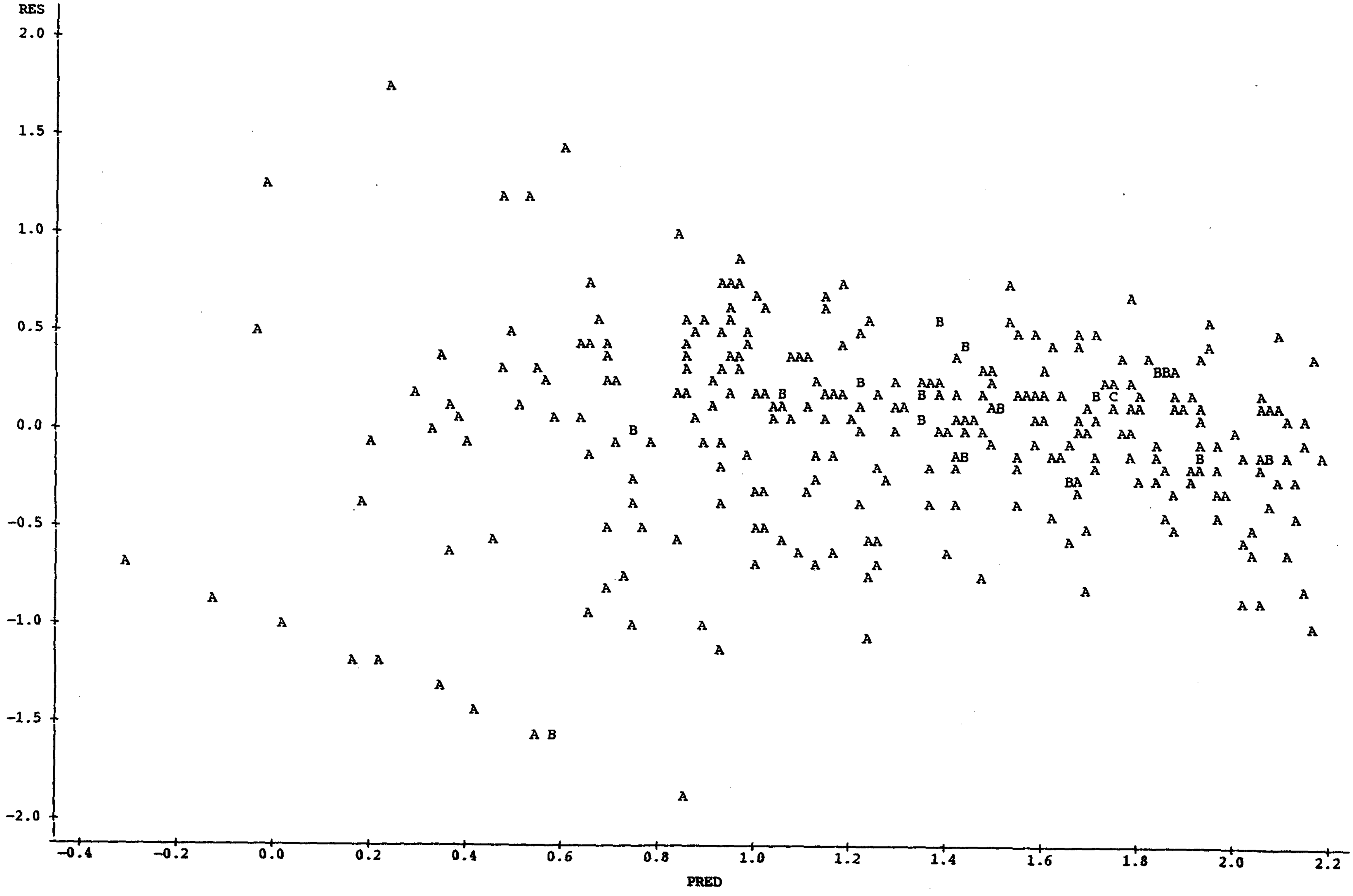

Figure 5. Residual vs. predicted values of log (fry abundance) in Miramichi River electrofishing sites regressed on log (egg deposition) with stream order, tributary and log (1+ and 2+ parr abundance) as covariates.

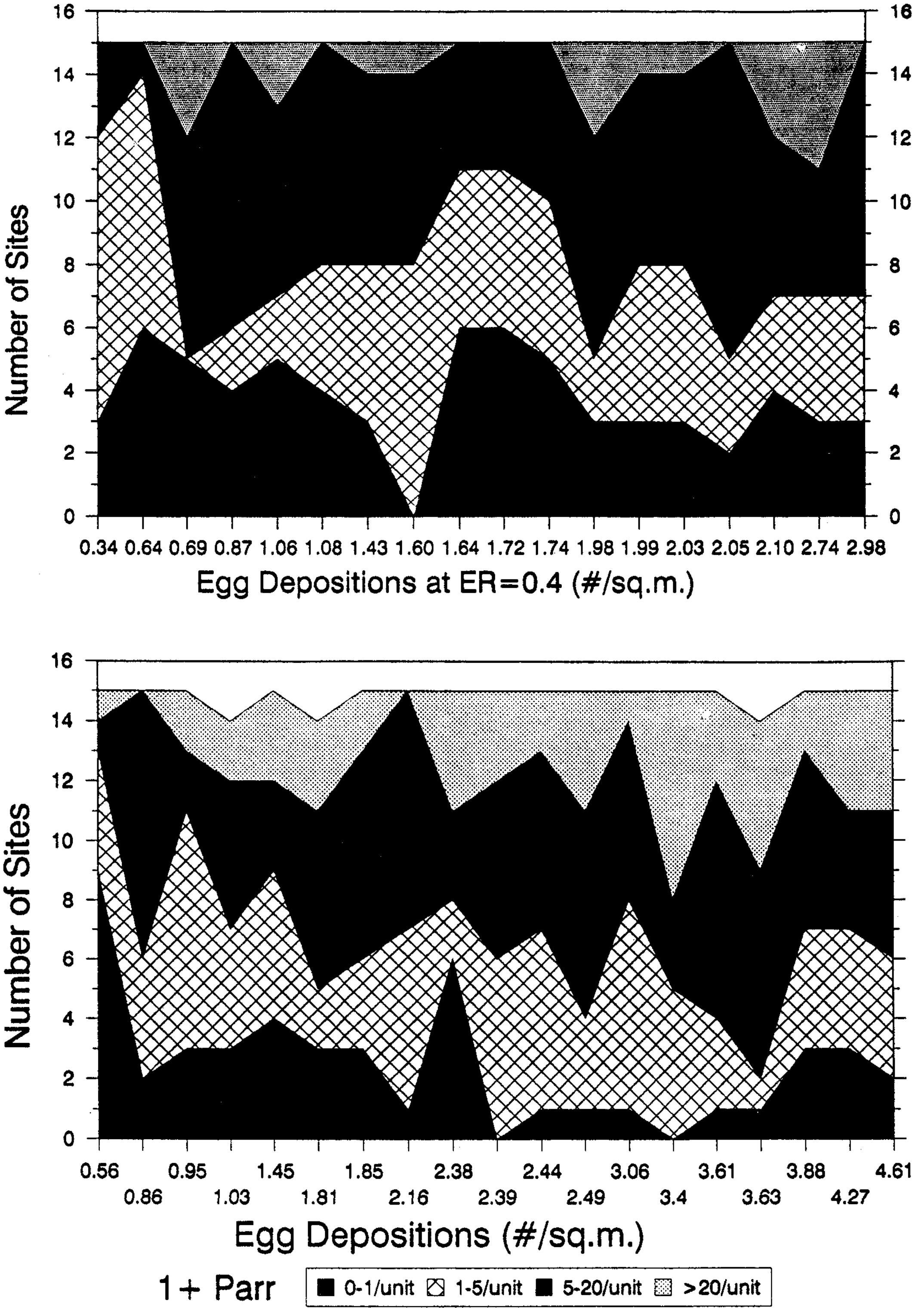

Figure 6. Parr (1+) abundance (no./m^2) in relation to egg deposition levels. (a) Restigouche River (egg depositions determined at angling exploitation rate (ER) = 0.4), (b) Miramichi River.

Plot of RESID*PRED. Legend: A = 1 obs, B = 2 obs, etc.

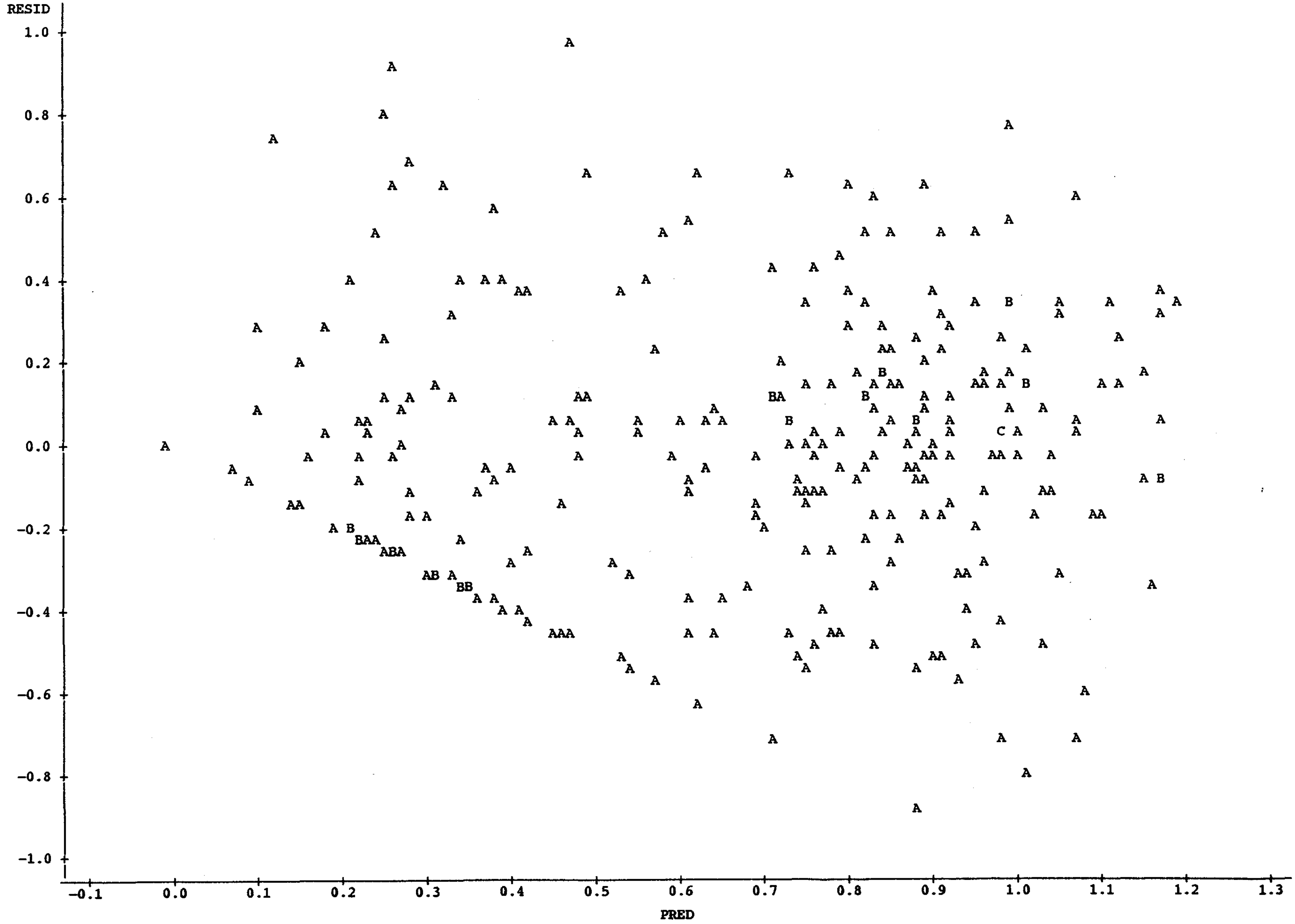

Figure 7. Residual vs. predicted values of log (1+ parr abundance) in Restigouche River electrofishing sites regressed on log (egg deposition), with Julian date, stream order and tributary as covariates.

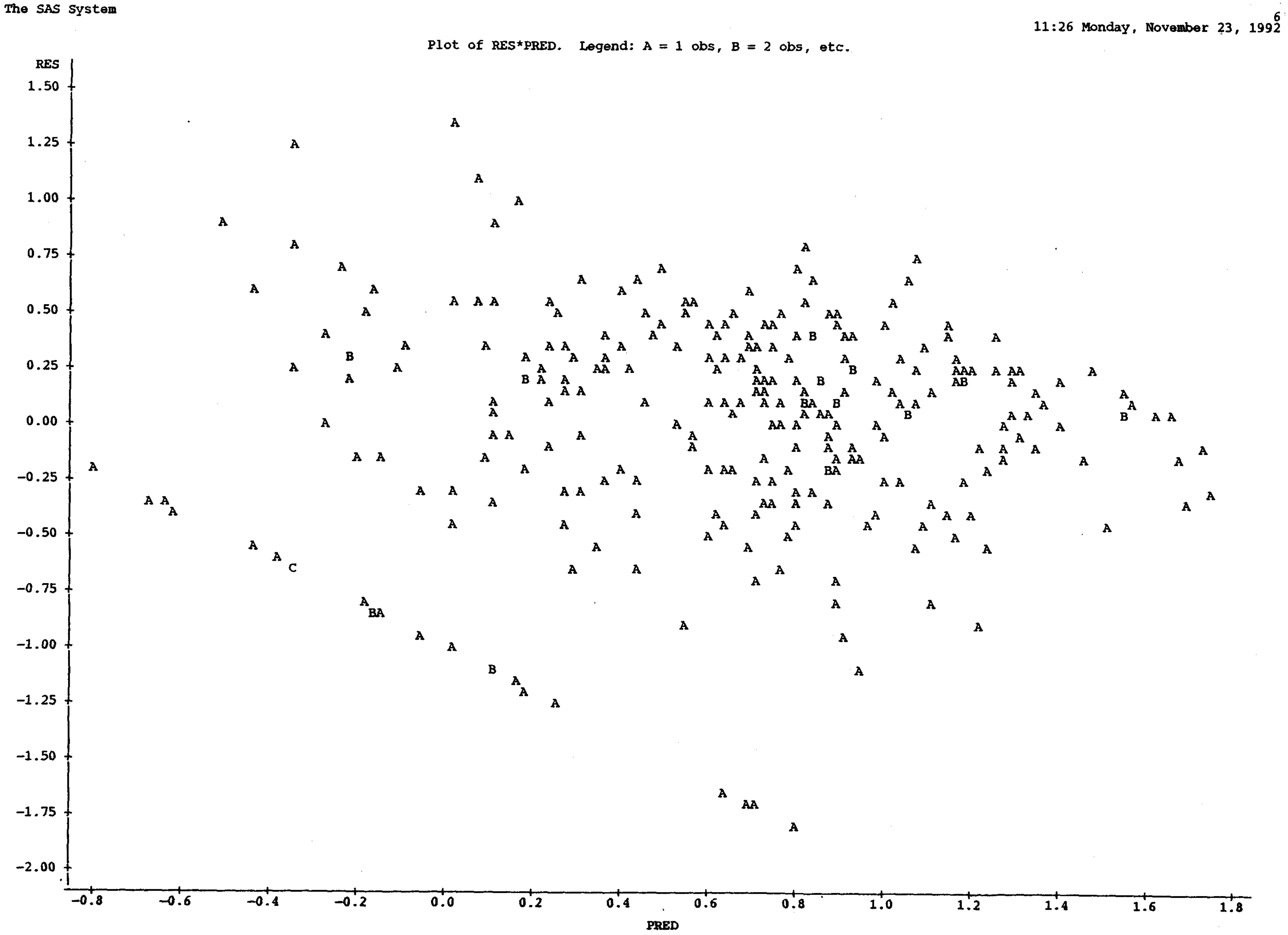

Figure 8. Residual vs. predicted values of log (1+ parr abundance) in Miramichi River electrofishing sites regressed on log (egg deposition), with stream order, tributary, elevation and gradient as covariates.

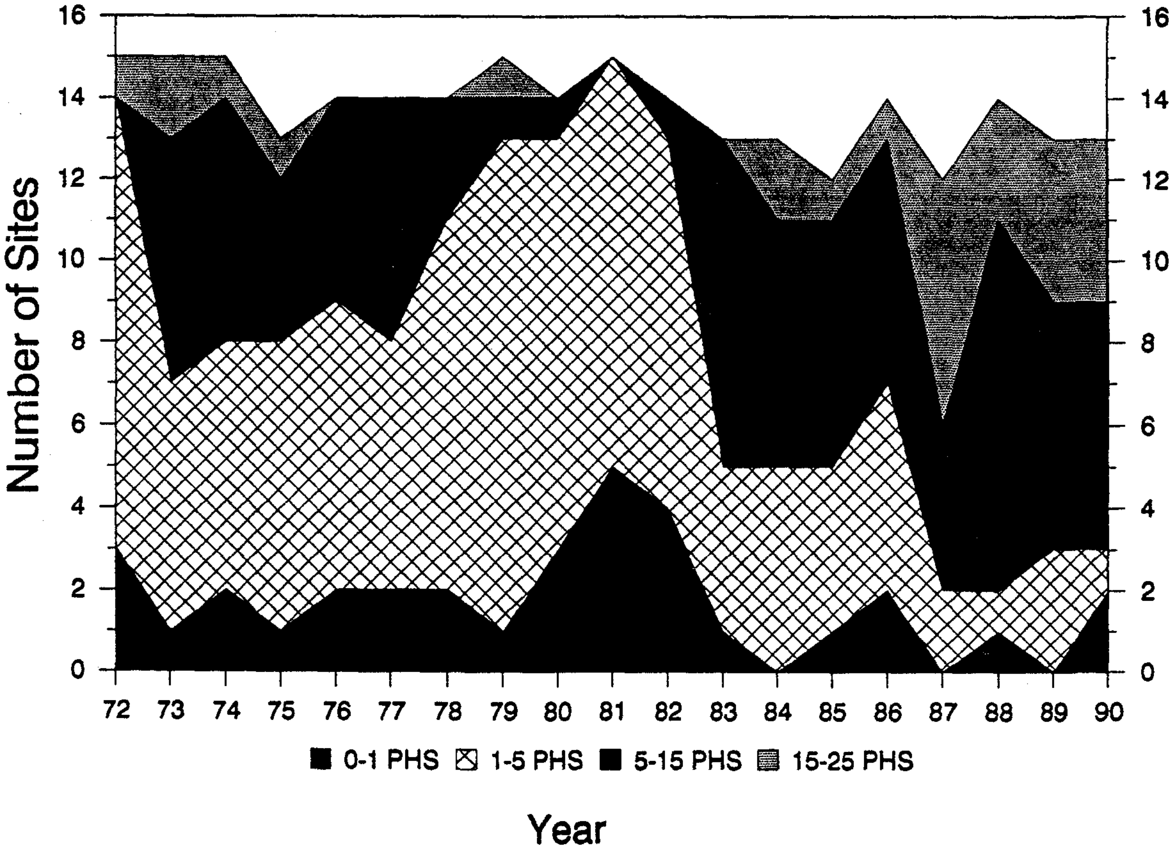

Figure 9. Percent habitat saturation (PHS) categories by year, Restigouche River.

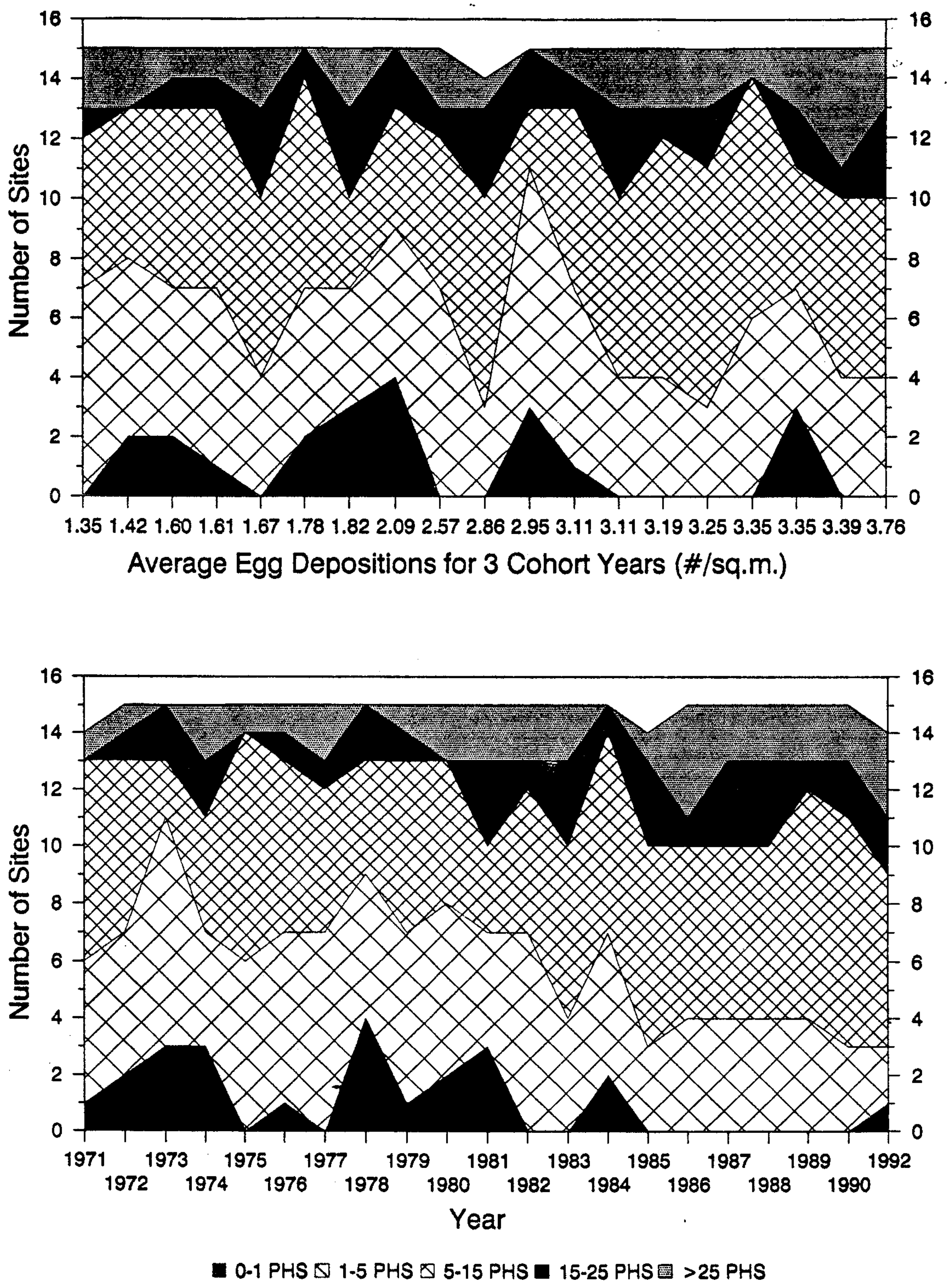

Figure 10. Percent habitat saturation (PHS) categories by year and for egg deposition averaged over three cohort years, Miramichi River.

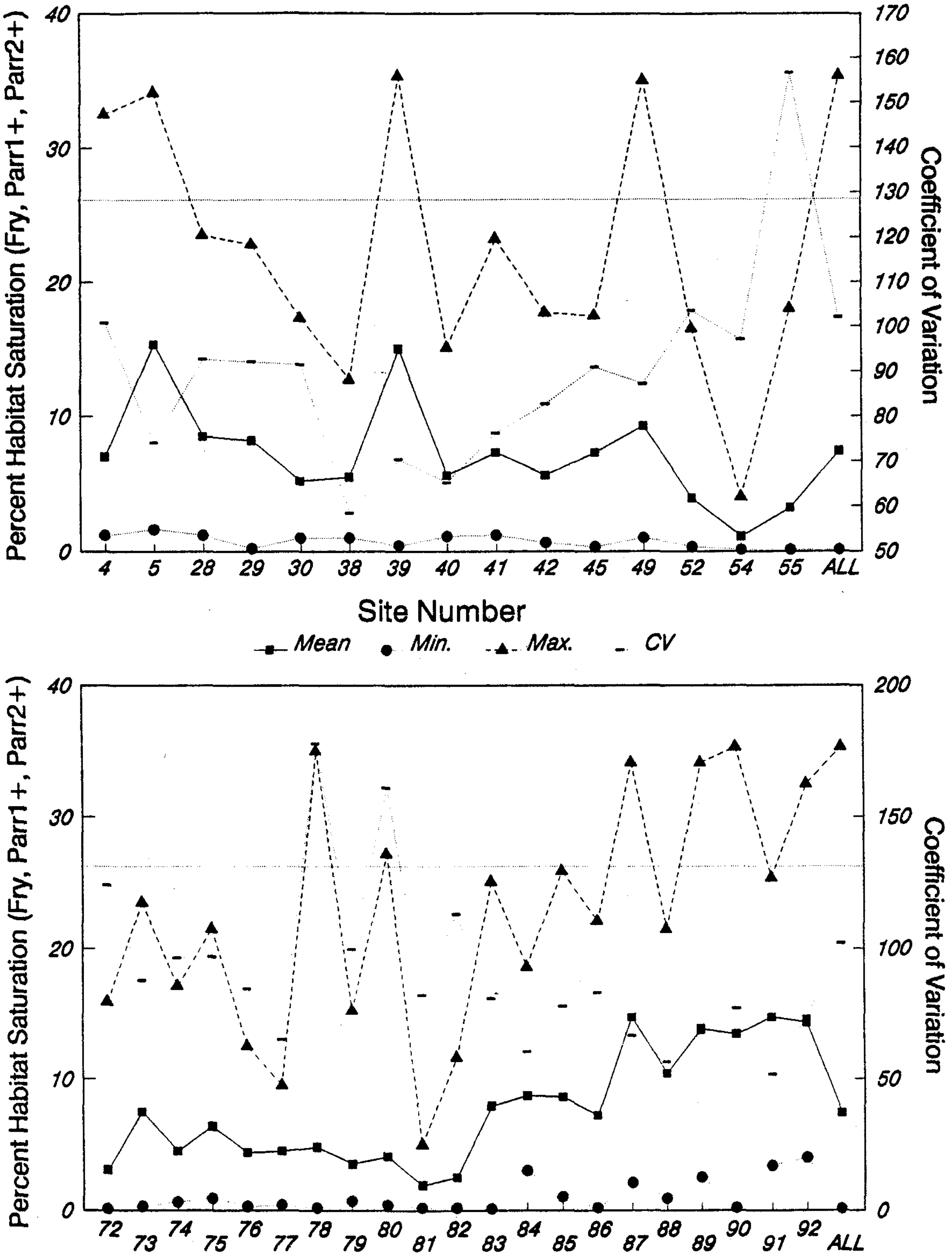

Figure 11. Variability in the percent habitat saturation by all ages of Atlantic salmon juveniles by site (over all years) and by year (over all sites) in the Restigouche River. The dashed line indicates the 27% saturation level.

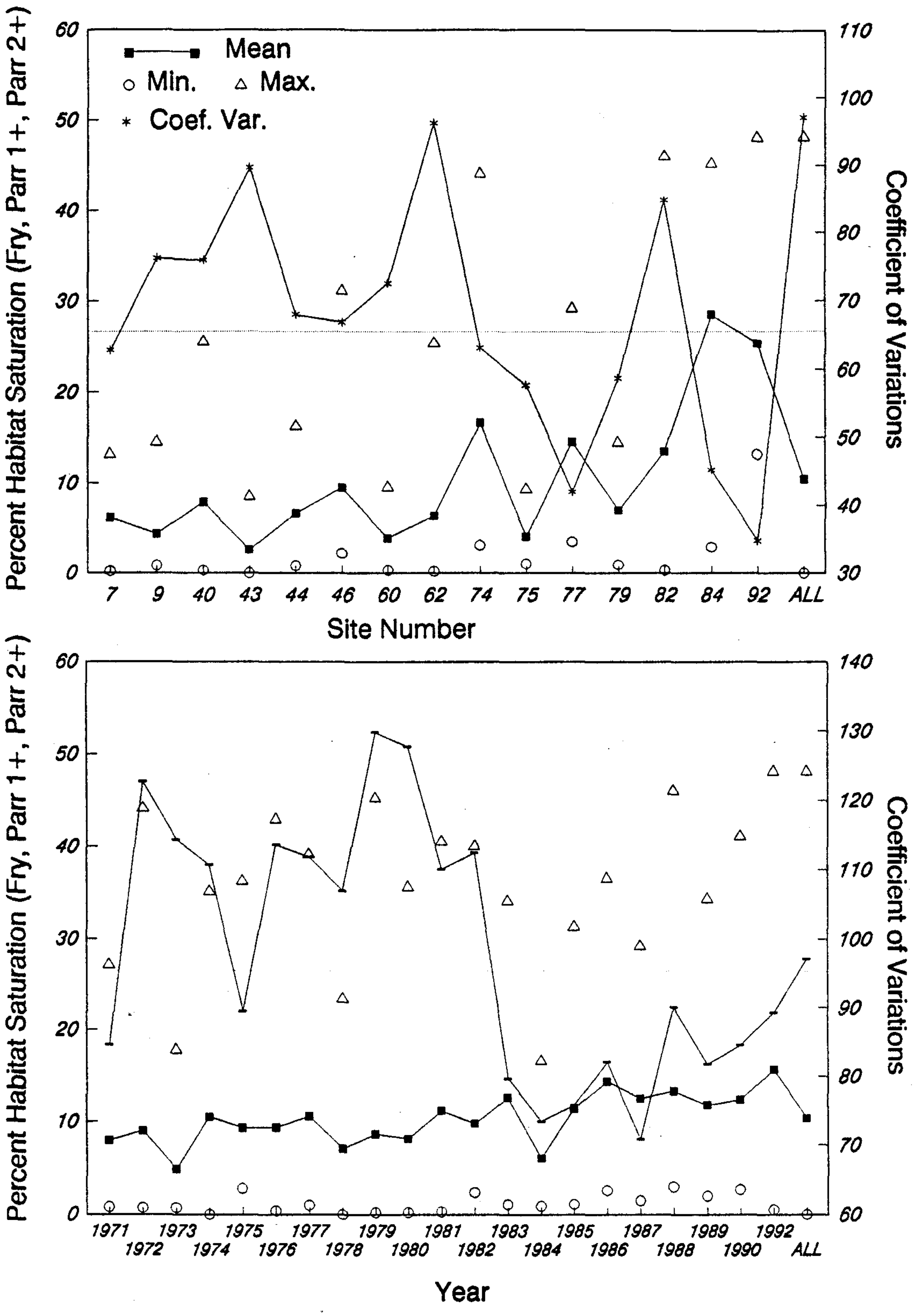

Figure 12. Variability in the percent habitat saturation by all ages of Atlantic salmon juveniles by site (over all years) and by year (over all sites) in the Miramichi River. The dashed line indicates the 27% saturation level.