The Biological Characteristics of, and Efficiency of Dip-net Fishing for, American Eel Elvers in the East River, Chester, Nova Scotia

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Abstract

In 1996, American eel elvers were first observed in the mouth of the East River, Chester, in late April and were first caught on April 27 when estuarine water temperatures were about 3 °C and river temperatures were about 8-10 °C. A commercial dip-net fishery for elvers was conducted about 100 m downstream of four elver traps, in turn situated just downstream of a natural falls, that were employed to estimate the escapement from the fishery, total run size, and fishery exploitation rate. About 331,000 elvers were taken in the dip-net fishery between April 17 and June 20 while 792,600 elvers were caught in the traps between May 4 and July 12. The total run was estimated at 1,123,600 (95% CI ± 50,200) elvers and the fishery exploitation rate at 29.5% (95% CI ± 2.6%).

Elver daily run size increased with increasing water temperature, initially decreased with increasing water level then increased after a lag of four days, and lagged rising maximum nighttime tide level by three days, thereby entering the stream as maximum nighttime tide level was declining. The difference in temperature between estuary and river had no effect on the daily upstream movement of elvers. The effect of the various environmental variables declined later in the run. Elver length decreased by 5%, weight by 26%, and pigmentation stage progressed from none (glass eel) to fully pigmented as the run progressed.

Introduction

The growth of the fishery for American eel (*Anguilla rostrata*) elvers in the Bay of Fundy areas of New Brunswick and Nova Scotia and along the Atlantic coast of Nova Scotia (Scotia-Fundy area) has been controlled by license, quota, and other restrictions since its begining in 1989 (Jessop 1995, 1996a). Such controls ensure that, in conjunction with existing moderate controls on the fisheries for larger eels (Jessop 1996b), the potential for overexploitation of the eel resource is minimized in specific rivers and regionally, thereby reducing possible negative effects on the continental stock. Numerous aspects of the biology of American eels are unknown or uncertain, including the sizes of elver runs in relation to river size and location and the capture efficiency of commonly used fishing gears. This study evaluates the efficiency, in terms of catch per hour of fishing effort, of the commonly employed dip-net, the rate of exploitation (catch as a proportion of the total elver run) by such a fishery, the seasonal duration, pattern, and size of the elver run and effects of environmental factors on the run, and elver length, weight, and pigmentation stage composition.

Study Area

The East River, Chester has a watershed area of 134.0 km^2, of which 10.5% is lake surface area, and drains into the East River Bay portion of Mahone Bay (Figure 1). It has two tributaries: Barry Brook (drainage area of 19.1 km^2 of which 1.9% is lake surface), which joins the main stem about 0.5 km upriver from the mouth, and the larger Canaan River (69.4 km^2 drainage area of which 4.8% is lake surface), which joins the main stem about 4 km upriver from the mouth. The main stem or East Branch drains an area of 45.5 km^2 of which 22.8% is lake surface. In the East River, the acidic pH (range 4.7-5.0) is influenced by water basin geology which, along the Atlantic coast of Nova Scotia, consists mostly of granite and metamorphic rocks of the Southern Upland overlain by shallow soils with poor drainage and containing numerous lakes and many bogs and heaths (Watt 1986). In the Canaan River tributary, annual pH values averaged 4.65 between 1981 and 1994 (range 4.22-5.04; Watt et al. 1995). The pH varies seasonally, falling rapidly in October and remaining low (typically about 0.5 pH units below the mean) between October and March, then rising slowly to a peak in September. The main stem (East Branch) lakes were treated with limestone between 1986 and 1995 as an acid mitigation project to preserve the native wild Atlantic salmon (*Salmo salar*) stock (Watt and White 1992). During the treatment period, mean annual pH values in the East Branch rose from about 5.3 to 6.7.

Atlantic salmon, brook trout (*Salvelinus fontinalis*), American eel, white sucker (*Catostomus commersoni*), lake chub (*Couesius plumbeus*), banded killifish (*Fundulus diaphanus*), and stickleback spp., were electrofished between 1983 and 1994 in the East Branch of the East River, Chester, and brook trout, American eel, white sucker, lake chub, and yellow perch (*Perca flavescens*) occurred in the Canaan River (W. White, Department of Fisheries and Oceans, Halifax, N.S., pers. comm.). American eels, with counts averaging 9.9 eel·100 m^{-2} in the East Branch and 7.4 eel·100 m^{-2} in the Canaan River were the dominant species, by a factor of at least 4.

The mouth of the East River, Chester drops about 1.1 m over a distance of 10.6 m (slope 0.11) between the small falls at the outlet of the pond and the high tide mark just upriver of the Highway 3 bridge (Figure 2). Most of the vertical drop occurs at the fall line or within 2-3 m of it. The presence of the rapids at the mouth of the river was a major factor in the selection of this river as the project site because of the expectation that the water velocities and vertical drops across the fall line between pond and outlet stream would prevent or delay upstream movement.

Methods

Four Irish style elver traps (O'Leary 1971) were operated at the mouth of the East River, Chester (Figure 2). Traps were sited on each side of the river immediately downstream of the small falls at the river mouth and further downstream at, or just upstream of, the tidal high water mark. Trap sites were selected with the objective of collecting all elvers migrating upstream. By-pass routes that developed as water velocities declined with seasonally reducing discharge or where elvers found a convenient, near-shore path around the main stream obstacles, perhaps provided by lower velocity, near-shore flows or damp, on-shore pathways, were blocked as they became evident. Attraction water for each trap was provided by gravity feed through hoses reaching the pond upriver of the falls. Ramps from the mouths of the traps to below river water level were extended constantly as the river level dropped throughout the elver run. Elvers entering the upper quarter of the trap were flushed by water flow into an associated holding box.

Elver catches were counted each morning for each trap. Individual elvers were counted when numbers were small; when numbers were large, the number was estimated volumetrically in roughly 50 ml aliquots in a calibrated graduate cylinder. Six calibration counts (nine at 50 ml) were made at each of four volumes (30, 50, 80, 100 ml) and the mean elver count at 50 ml (198, SD = 18.40) was used as the calibration constant. The linear regression relating elver count (Y) with cylinder volume (X) was $Y = 0.235 X + 4.465$ ($N = 26$, $r^2 = 0.98$, $P < 0.0001$; one outlier count at 100 ml was omitted). The calibration at 50 ml was repeated half-way through the run (June 5) and the new calibration value (192, SD = 5.92) used from then on, although the two calibration constants did not differ significantly ($F_{1,16} = 0.87$, $P = 0.37$).

On Mondays, Wednesdays, and Fridays a representative sample of up to 50 elvers, as available, was killed in 5% formalin then immediately measured for total length (TL, to 0.1 mm) by digital caliper, weighed (to 0.1 g) after blotting dry, and categorized for pigmentation stage using the criteria and coding of Haro and Krueger (1988). All elvers not sampled for biological data were released alive upriver about 75 m from the falls at the river mouth. Juvenile eels, initially categorized as greater than 70 mm TL, 0.30 g in weight, and pigmentation stage 7 were separated from the elvers, counted and processed for biological data as were the elvers except that lengths greater than 150 mm were measured to the nearest millimeter. Larger juvenile eels were anaesthetized with MS-222 prior to measurement then released alive.

In the absence of age data and the possible overlap at the upper extremes of glass eel/elver (age 0) and lower extremes of juvenile (age 1+) eel length and weight distributions, eels were subsequently categorized as age 0 if the following criteria were met: 1. ≤ pigmentation stage 5; 2. ≤ 70 mm and/or 0.30 g, and pigmentation up to stage 7 before June 1; 3. ≤ 75 mm and/or 0.35 g, and pigmentation up to stage 7 after June 1, otherwise they were categorized as age 1 (and older). This categorization was based on a length and weight frequency and pigmentation stage analysis of the catch and on similar studies of the elver data from the East River, Sheet Harbour (Jessop, unpublished data). The number of eels of uncertain age categorization was about three percent of all sampled eels ($N = 1,639$).

Water temperatures (to 0.1 °C) were recorded every two hours by thermographs set in the East River upriver of the falls and in the estuary about 0.5 km from the river mouth. As a proxy for river discharge, relative river water level in the pond upriver of the falls was measured daily to 0.25 cm on a staff gauge installed on May 8. Cloud cover, in tenths of sky cover averaged over the day, was recorded daily. Nighttime maximum tide heights (relative to Halifax harbour) were obtained from hourly records of the tide height (to 0.01 m) at Halifax harbour (R. Menard, Marine Environmental Data Service, Ottawa, personal communication). Tidal patterns in Halifax harbour and Mahone Bay are similar although the absolute heights in Mahone Bay are 0.15 m higher than in Halifax harbour (Anon. 1996). Near-shore (about 15 cm from shore and 10 cm below the surface) water velocities were measured with a Marsh-McBirney electromagnetic flowmeter (to ± 2% of reading) on Mondays, Wednesdays, and Fridays at seven locations: adjacent to each trap (sites 1-4), just upriver of the lip of the falls on each bank (sites 5 and 7), and midway between the falls and trap 1 on the true right bank (site 6). The correlation between daily mean water velocity and water level was estimated after both variables were detrended of seasonal decline effects by differencing (Wilkinson et al. 1996).

The possibility that elvers could bypass the main stream obstructions was investigated by periodic nighttime (between dusk and midnight) surveys of the shoreline area to detect elver upstream movement and then prevent it by blocking all pathways by physical barriers, e.g., filling in damp, low spots or blocking narrow channels along the shore where low water velocities occurred so as to force elvers back into the main stream.

Dip-net fishing (net diameter = 76 cm, depth = 20 cm, mesh = 1 mm^2) for elvers was conducted in a standard manner by two fishers in the area downstream of the Highway 3 bridge and about 100 m downstream of the lowermost trap (Figure 2). Nightly catches (to 0.1 kg, drained weight) and fishing effort (to 0.25 hr) were recorded in a logbook. Dip-net fishing efficiency (FE) was calculated as FE(%) = fishery catch/(fishery catch + trap catch) x 100, assuming that the total run = fishery catch + trap catch. Fishery catch (kg) was converted, on a weekly basis, to elvers by subtracting 25% of the weekly catch weight as representing adhered water (W. Carey, elver fisher, personal communication) then multiplying by the number of elvers per kg, based on the weekly mean weight of sampled elvers. Commercial fishing activity ceased when nightly catches were judged insufficient to justify further effort; the elver traps were operated until daily catches averaged less than 100 elvers.

The effects of environmental variables on the start and pattern of elver migration were analyzed by multiple linear regression according to the model:

$$E = B_0 + B_1 T + B_2 H + B_3 M \qquad (1)$$

where: E = daily elver trap total count; B_0 = intercept; B_i = coefficient for each parameter; T = daily mean river water temperature; H = daily river gauge height (level); M = maximum tide height for the night preceding the elver count. The hypothesis that the difference between river and bay water temperatures influences the daily elver count, rather than just river water temperature as in model 1, was tested by substituting $\Delta T = (T_r - T_b)$ for T in model 1, where ΔT = the difference between mean daily river and bay water temperatures:

$$E = B_0 + B_1 (\Delta T) + B_2 H + B_3 M \qquad (2).$$

River temperature was not significantly correlated with temperature difference ($r = 0.09$, $P = 0.42$, $N = 75$), nor were lag effects evident, so temperature difference was considered independent of river temperature. Model 1 will be termed the river temperature model and model 2 the temperature difference model hereafter.

Daily plots of each variable indicated that the elver run could be usefully divided into two segments (up to and after June 11) based on trends in the river and bay water temperatures and river gauge heights. Thus, river and bay water temperatures significantly increased up to about June 11 then leveled off while river gauge heights fluctuated with no trend to about June 11 then declined significantly. Spurious correlations between the daily elver count and environmental variables, e.g., due to the seasonal increase in river water temperatures and decline in water levels ($r = -0.87$, $P < 0.001$, $N = 67$), were avoided by differencing the time series once to achieve stationarity (no time trend) and to reduce the autocorrelation (correlation between a value and a previous value) within the time series and achieve independence (no correlation between values) of residuals (the difference between the regression line and observed value) (Wilkinson et al. 1996).

Correlations between differenced values of the daily elver count (logarithmically (base 10) transformed (X + 1) to reduce the non-normality of the distribution of counts) and environmental variables were examined for lag effects, i.e., a delay of one or more days between occurrence of an environmental change and any effect on daily elver count. The daily elver count (to June 11) was significantly, and most highly, correlated ($r = 0.43$, $P = 0.016$, $N = 31$) with river level after a four day lag, with river temperature after a one day lag ($r = 0.47$, $P = 0.003$, $N = 37$), with night tide after a three day lag ($r = -0.41$, $P = 0.013$, $N = 37$), and marginally with the temperature difference between river and bay after a one day lag ($r = 0.29$, $P = 0.08$, $N = 37$). Lagged river level, temperature, temperature difference, and night tide values were used in the multiple linear regressions. Despite marginal non-significance, lagged temperature difference values were used because the regression fit was usefully improved. Output from both models with all variables included and with non-significant variables deleted (the "best" model) has been presented for completeness. Residual plots of various types revealed no serious violations of the assumptions underlying the use of regression models. Studentized residual values, leverage measures, and Cook's D statistic indicated no unduly influential data points and the Durbin-Watson statistic, which evaluates autocorrelation of residuals from the fitted regression, was within acceptable limits (around 2). Statistical significance has been accepted at $P \leq 0.05$.

The weight-length regression, with data logarithmically (base 10) transformed, was based (Ricker 1975) on subsamples of up to 60 elvers (minimum subsample of 51 elvers) randomly chosen from each 5 mm length interval over the observed 50-75 mm length range, with two elvers of 76 mm included (a subsample of 288 elvers from a total of 1,347 elvers).

Weekly mean lengths, weights, and pigmentation stages of elvers were compared by one-way analysis of variance (ANOVA), with multiple pairwise comparisons of means by the Tukey-Kramer HSD method.

Results

Elver Fishery and Run

The commercial elver dipnet fishery was conducted on 33 nights between April 27 and June 20. No fishery occurred during periods when the tides were judged unlikely to favour reasonable catches, e.g., falling tides between late afternoon and midnight. Elvers were first caught in late April, then none were caught until mid-May. Catches peaked June 2 (about 43,000 elvers; 10.66 kg), then declined steadily until cessation of fishing on June 20 (Table 1; Figure 3). The fishery catch totaled 86.34 kg or an estimated 331,060 (95% CI ± 14,300) elvers. The mean catch per unit fishing effort (CPUE) was 0.34 $kg \cdot hr^{-1}$ ($N = 33$, $SD = 0.362$, range 0.0-1.35 $kg \cdot hr^{-1}$).

The elver traps became operational on May 4 with the first catch recorded on the morning of May 5, after which few elvers were caught until May 16 when a wave of elvers entered the river (Figure 3). Four rather sharp peaks and one more diffuse peak of varying magnitudes occurred during the run with a mean time between peaks of 6.8 d (range 5-9 d). Peaks in the trap catches were preceded, by 1-3 days, by peaks in the commercial fishery catch. Over 80,000 elvers were caught during each of the two highest peaks in late May and early June. Small catches (usually less than 200 elvers) continued during July until project termination on July 12. Total catch was estimated as 792,590 (95% CI ± 35,880) elvers. Juvenile eels were first caught on May 18 and, although much less abundant (catch = 771 eels) than elvers, displayed run peaks similar to those of elvers until mid-June after which they also declined in abundance (Figure 4). Early in the run, elver migration occurred at night but, by mid-run, daytime activity of lesser magnitude than at night was observed for a time, after which night migration again dominated.

Total elver catches varied among the four traps, with the upriver left and right bank traps (looking upstream) catching similar total numbers (206,650 vs 213,610) while the downriver right bank trap caught almost three times as many (271,790 vs 100,540) as the lower left bank trap (Table 1; Figure 5). The upriver traps continued, after about mid-June, to fish more effectively than did the downriver traps. Peak catches also varied in magnitude among traps but were similar in date of occurrence.

The elver run to the East River, Chester was estimated at 1,123,650 (95% CI ± 50,180) elvers. Fishing efficiency, or exploitation rate, by dipnetting was estimated at 29.5% (95% CI ± 2.6%).

Elver Instream Movements

Shoreline physical conditions changed with fluctuating water levels and velocities. Water velocity, as expected, was highly correlated ($r = 0.77$, $P < 0.0001$, $N = 27$) with river water level. Both water level and velocities were high early in the elver run, fluctuating in response to rainfall events, then declined steadily after early June (Figure 3; Figure 6). Water velocities just upriver of the lip of the falls averaged 173 $cm \cdot s^{-1}$ (range 121-228 $cm \cdot s^{-1}$) until June 11 after which they steadily declined to 108 $cm \cdot s^{-1}$ (June 12-18), 89 $cm \cdot s^{-1}$ (June 19-25), 58 $cm \cdot s^{-1}$ (June 26-July 2), and 50 $cm \cdot s^{-1}$ (July 3-9) before rising to 80 $cm \cdot s^{-1}$ (July 10-13). Water velocities declined downstream of the falls as the river slope flattened beyond about the first 3 m from the falls, within which a drop of about 0.6 m occurred at the fall line. Thus, during May (weeks 1-4), average water velocities decreased from about 175 $cm \cdot s^{-1}$ at the falls to 135 $cm \cdot s^{-1}$ at site 6, midway between the falls and the uppermost trap (1), to 75 $cm \cdot s^{-1}$ at trap sites 1 and 2. After June 11, average water velocities at the trap sites declined to about 40-50 $cm \cdot s^{-1}$ except at site 4 where they were less than 20 $cm \cdot s^{-1}$.

No signs were observed of elver movement upstream beyond the fall line or bypassing the traps before early June. During the first week of June, a few to several hundred elvers were observed clustered at choke points, e.g., water chutes in the nearshore area between boulders with damp sides that some elvers could climb or in damp areas 0.5-2 m inshore of the stream edge, upriver of the traps and below the fall line. Some elvers may have progressed into the pond upriver of the fall line prior to first detection but it is believed that few did so because, despite much activity, few were observed to actually pass the more significant obstacles. By June 12, all potential bypass areas had been filled in by dirt or cement (elvers actively avoided wet cement) and potential escapement to the upriver pond was believed to have been halted. However, on June 18 an escapement of perhaps less than 100 elvers was observed before the movement was halted. Subsequent night observations indicated no apparent movement of elvers beyond the fall line.

Environmental Effects on Run Timing

Small numbers of elvers were present at the mouth of the East River, Chester, in late April (W. Carey, elver fisher, personal communication) and were first caught on April 27 when estuarine water temperatures were likely about 3 °C and river temperatures about 8-10 °C (Figure 3; Figure 7). Elvers first entered the traps when mean daily water temperatures were 3.5 °C in the estuary and 10.0 °C in the river. Daily water temperatures in bay and river increased gradually, with moderate trend fluctuation, until early June then increased more rapidly until mid-June after which they essentially leveled off. The difference in water temperature between estuary and river fluctuated about the mean of 4.45 °C throughout most of the run before declining during July (Figure 8). River water levels periodically fluctuated 20-30 cm in response to rainfall until early June, then declined steadily until mid-July when rainfall increased the water level.

When all environmental variables were included in the model, neither the river temperature nor the temperature difference multiple linear regression models showed significant effects by environmental factors on the elver run count for the period to May 25, which was the peak of the second pulse of elvers entering the river (Tables 2 and 4; Figure 3). As the third and fourth pulses of elvers peaked successively on June 3 and 11, river temperature ($P < 0.03$) had a positive effect and night tide level ($P < 0.005$) a negative effect on daily elver count in the river temperature model while river level had a positive effect ($P < 0.04$) and night tide a negative effect ($P < 0.02$) in the temperature difference model. After June 11, no environmental factor significantly affected daily elver counts. The non-significance of river level in the river temperature model and significance in the temperature difference model results from collinearity between water temperature (lagged one day) and river height or discharge ($r = -0.42$, $P = 0.004$, $N = 66$), where water temperature decreases with increased discharge.

The *t*-values of Tables 2 to 5 provide information on the positive or negative nature of the relationship, the associated *P*-values indicate the relative importance and probability of such a *t*-value occurring, with significance accepted for probabilities less than or equal to 5%. The adjusted multiple R^2 value is the fraction of the total variation in the response variable accounted for by the regression and adjusted for the number of predictor variables. The relatively low R^2 values reflect the high variability typical of environmental and fish count data. The final *P*-value indicates the significance of the linear relations between the daily elver count and the various environmental variables.

Dropping the non-significant variables river height from the temperature model (1) and temperature difference from the temperature difference model (2), as required by statistical procedure, improved the significance of all three environmental variables (Tables 3 and 5). Note that dropping temperature difference from the temperature difference model (2) makes it equivalent to the temperature model (1) but with river temperature replaced by river height. These models will hereafter be termed the reduced temperature (1a) and river height (2a) models. For the reduced river temperature model (1a), daily elver count was positively associated with river temperature and negatively with night tide height between May 25 (May 18 for tide height) and June 11, while after June 11, no environmental variables were significant (Table 3). For the river height model (2a), daily elver count was positively related to river water level and negatively with night tide height between June 3 and June 11, while after June 11, environmental variables were non-significant (Table 5). The standardized coefficients for all environmental variables ranged between 0.39 and 0.49 in the reduced models, indicating that each had similar effects on the daily elver count. Three of the four major elver run peaks occurred when tides were rising between 1600- 2000 h and falling between 2000-2400 h while the fourth peak occurred when tides between 1600-2000 h were falling and rising between 2000-2400 h.

Elver Biological Characteristics

Total Length and Weight

The total sample ($N = 1,347$) of elver lengths was roughly normally distributed, with a mean of 62.24 ± 0.23 mm (95% CI), median of 61.96 mm, and range from 50.3 to 76.1mm (Figure 9). Elver weights were right skewed, with a mean of 0.179 ± 0.002 g (95% CI), median of 0.170 g, and range from 0.07 to 0.38 g. Elver mean (median) length increased for the first three weeks of the run from 61.71 (62.25) mm to 64.06 (64.25) mm then steadily declined to 60.58 (60.27) mm at the end of the run while elver mean (median) weight decreased steadily throughout the run from 0.23 (0.23) g to 0.15 (0.14) g (Figure 10). Elvers declined about 3.5 mm (5%) in length and 0.05 g (26%) in weight between mid May and mid July. Both unusually long elvers and unusually heavy elvers appeared early in the run but unusually heavy elvers tended to be more abundant later in the run. High lengths were not necessarily coupled with high weights. Weekly means varied significantly for elver length ($F = 7.26$, df = 10, 1,336, $P < 0.0001$) and weight ($F = 27.88$, df = 10, 1,336, $P < 0.0001$). Weekly means that are underlined are non-significantly different:

Week	3	2	5	4	7	8	6	1	9	10	11
Length	64.06	63.71	63.17	62.93	62.86	61.90	61.72	61.66	61.39	61.15	60.58

Week	1	3	2	4	6	5	7	8	9	11	10
Weight	0.231	0.206	0.204	0.197	0.195	0.187	0.184	0.164	0.156	0.153	0.144

Groups of length and weight measurements that are underlined are not significantly different from each other; whether any two values are significantly different must be determined by considering all underlines.

Juvenile lengths and weights were right skewed; few individuals exceeded about 100 mm in length and 1.5 g in weight (Figure 9). A few larger juvenile eels entered the traps between June 5 and June 18 (weeks 6 and 7; Figure 10).

Elver weight increased in a slightly curvilinear manner with increasing length over the length range 50-76 mm (Figure 11A). Increased variability at the extremes of the data distribution is caused by short and long elvers that are unusually heavy for their length. The predictive linear equation describing the relation is:

$$\text{Log}_{10} W = -6.3207 + 3.1058 \text{ Log}_{10} L \qquad n = 288,\ R^2 = 0.78,\ P < 0.0001$$

where W = weight (g) and L = length (mm) (Figure 11B). The standard errors and 95% confidence bounds (in parentheses) for the regression coefficients are: constant = 0.1742, (-6.6636 to -5.9778); Log_{10} L = 0.0971, (2.9148 to 3.2969).

Pigmentation

The degree of elver pigmentation increased progressively over the run, with most elvers in pigmentation stage 2 during May 1-7, stage 4 by May 29-June 5, and stages 6 and 7 by July 10-16 (Figure 12). Pigment stage 1 (glass) elvers were not found after May 10 and were moderately abundant (33%) only during the first week of the run while a few stage 7 elvers appeared as early as May 20. Glass eels composed less than 0.002% of the trap catch but were likely more abundant in the early (late April) fishery catch. Five elvers were found on May 10 with pigment stages 1-3 but between 71 and 76 mm long and weighing 0.25-0.38 g (median 0.30 g).

Discussion

Elver runs to the rivers of the Atlantic coast of North America generally, and of Nova Scotia specifically, vary in their run timing, being generally earlier in southern than in northern coastal areas (Fahay 1978; Jessop, In review). Elver migration occurs in three phases: coastal approach, estuarial phase with transition from sea to freshwater, and upstream migration and distribution within the river (Cantrelle 1982). In the upper estuary of the East River, Chester, elvers appeared in late April but the first major wave of elvers did not enter freshwater until mid May. Annual variability, over eight years, of about 1-2 weeks in both the start of the elver run and appearance of the first run peak occurred in the East River, Sheet Harbour (Jessop, unpublished data). Delays of several weeks, or even months, may occur between the first arrival of glass eels and the movement of glass eels and more pigmented elvers upriver and may represent a period of physiological adjustment to estuarine conditions (Deelder 1958; Creutzberg 1961; Tesch 1977; Sorensen and Bianchini 1988; Haro and Krueger 1988; Dutil et al. 1989). During this holding period in the estuary, behavioural changes occur in the elvers preparatory to upstream migration, including increased gathering near the surface, decreased light avoidance, more gregarious behaviour, and active movement towards freshwater (Cantrelle 1982; Élie and Rochard 1994). Once migration had begun, the delay of 1-3 d between run peaks in the estuarine dipnet fishery and freshwater trap catches may represent a final period of physiological adjustment or simply the time necessary to move upstream during high water levels. Elver migration occurs at night except during mid-run when a window of daytime activity occurs before night migration again predominates (Deelder 1958; Cantrelle 1982; Gandolfi et al 1984; Dutil et al. 1989). Division of the elver run into several waves of varying magnitude is typical for American eels (Groom 1975; Martin 1995; Jessop, unpublished data) and for European eels (Élie 1979; Cantrelle 1982). Small numbers of juvenile eels also migrate upstream throughout, or later in, the elver run, as also occurs for European eels (Cantrelle 1982; Vøllestad and Jonsson 1988).

The 1996 estimated run of 1.12 million elvers to the East River, Chester (drainage area of 134 km^2) and run density of 8,400 elvers$\cdot$km^{-2} of river drainage area greatly exceeds the run of 0.34 million elvers to the East River, Sheet Harbour (drainage area of 526 km^2) and density of 640 elvers$\cdot$km^{-2} (Jessop, unpublished data). Elver run size and density estimates are unavailable from other North American rivers but, in Europe, run densities averaged 159 elvers$\cdot$km^{-2} (range 20-380 elvers$\cdot$km^{-2}) over nine years in the Imsa River, Norway (drainage area of 128 km^2) (Vøllestad and Jonsson 1988), and 561 elvers$\cdot$km^{-2} in the River Arguenon, France (drainage area of 383 km^2 (Legault 1994). Thus, the hypothesis that elver runs are proportional to river discharge (drainage area) may apply only within geographic areas of similar elver abundance in coastal waters since elver catches vary over wide geographic areas in North America (Jessop, In review) and in Europe (Moriarty 1990a, 1992). An unknown, possibly small, portion of the elver migration to Mahone and East River bays become estuarine resident and do not enter a river.

The effectiveness of the falls as a barrier to upstream movement by elvers is critical to obtaining an accurate estimate of the size of the elver run. Current flows exceeding 120 cm$\cdot$sec^{-1} at the lip of the falls, a drop of about 0.6 m at the fall line, and active measures to prevent elvers from moving upstream are believed to have virtually eliminated any such movement. American elvers have difficulty swimming short distances or cannot maintain position at water velocities greater than 35 cm$\cdot$sec^{-1} and most will not swim at water velocities exceeding 25 cm$\cdot$sec^{-1}, tending instead to rest in the stream substrate (Barbin and Krueger 1994). McCleave (1980) concluded that swimming by American elvers is limited by water velocities exceeding 40 cm$\cdot$sec^{-1} and the larger European elver by water velocities exceeding 50 m$\cdot$sec^{-1}. Waterfalls of even a few centimeters are impassable to elvers but they may be bypassed when suitable conditions exist, such as at stream edges where water velocity and turbulence are not excessive and damp surfaces of suitable slope (up to vertical) and roughness may be climbed (Legault 1988). However, the success at bypassing obstacles may be illusory, particularly where water velocities on reentrance are excessive, and clearing rates may be low. The nature of the river channel, with a sharply defined edge marked by large rocks, limited the number of potential bypass sites to three or four and made blocking them relatively easy.

Dipnet fisheries are generally believed to be inefficient relative to other gear types but many fishers dipnetting a specific area may have a large effect (Cantrelle 1982). A dipnet fishery exploitation rate of 29.5% may be sufficiently low that compensatory biological effects, e.g., increased survival rate at lower elver densities, may reduce the impact of a fishery on future instream stock size to a minor level (Hilborn and Walters 1992), given the presumed high rate of natural mortality at this life stage. Survival rates of European elvers during their first year in a freshwater pond have been estimated at 47-88%, decreasing with increasing stocking density for densities of 160-1,600 elvers per hectare (Klein Breteler 1992). Density-dependent mortality may not become effective until a threshold density has been achieved, but once exceeded, the yield of larger eels declines as elver numbers increase (Vøllestad and Jonsson 1988). On larger rivers, the efficiency of dipnetting probably declines but verification of this assumption may be difficult.

Elvers evidently migrate only a short distance, perhaps a few kilometers, upstream during their first year in freshwater streams with moderate-to-high flows and gradients (Haro and Krueger 1988; Dutil et al. 1989). American elvers migrated upstream at about 6 $m \cdot d^{-1}$ in a stream with 2.2% gradient (Haro and Krueger 1988), resulting in a less than 1 km upstream movement during the first year while less than 4 km was attained in a Quebec stream with steep gradient (Dutil et al. 1989). At migration rates of 6 and 12 $m \cdot d^{-1}$, elvers could move upstream 0.7 to 1.5 km during a migratory period from June 15 to October 15, when water temperatures decline to about 10 ºC and eel activity is much reduced (Walsh et al. 1983).

If elvers remain within 2.5 km of the mouth in the lower East River, Chester, the resultant density of 97,000 $elvers \cdot ha^{-1}$ could produce first year mortality rates higher than at lower densities. This density exceeds the maximum stocking rates (1,600 $elvers \cdot ha^{-1}$) utilized or recommended (100-500 $elvers \cdot ha^{-1}$) in Europe (Moriarty 1990b; Moriarty et al. 1990; Klein Breteler 1992), although densities as high as 10,000-15,000 $elvers \cdot ha^{-1}$ have been used in some highly productive Danish streams (Berg and Jørgensen 1994). Achieving a density of 20,000 $elvers \cdot ha^{-1}$ in the lower 2.5 km of the East River, Chester would require an escapement of 162,800 elvers or about 15% of the observed run.

The estimates of run size and fishing efficiency have high precision but may be biased low by the assumption that catch weights require a 25% reduction to account for adhered moisture during weighing. This weight adjustment factor requires verification. Without the adjustment factor, the dipnet fishery exploitation rate would be 34.3%. Unaccounted-for elver escapement, which is believed to have been low or negligible, would further inflate the estimate of dipnet fishing efficiency.

Elvers entered the river in large numbers only after river temperatures reached 10 °C, a value similar to the 11 °C threshold suggested by Helfman et al. (1984) for a Georgia (state) river, 14 °C reported in Rhode Island (Sorensen and Bianchini 1986), and 10-12 °C for New Brunswick (Smith 1955; Groom 1975). Reports that elver runs peak during periods of rising water temperature and declining level, e.g., Groom (1975) and Haro and Krueger (1988), provide little insight into the true effects of such environmental conditions because these are the conditions that generally prevail during spring in North America when anadromous fish and elvers migrate upstream. Seasonal trends in, and correlations between, environmental effects, e.g., the negative correlation between water level and temperature, and lags in the action of environmental factors on elver migration must be accounted for (Sorensen and Bianchini 1986; Martin 1995). Once elvers had begun moving upstream, their abundance and seasonal pattern of movement were significantly influenced by river temperature, river level, and nighttime tide height until June 11, during which time 93% of the elver run had entered the river. After June 11, environmental conditions no longer had a significant effect on the remaining portion of the elver run - perhaps because too few elvers were available to respond detectably to the environmental effect, river temperatures had tended to level out at a temperature sufficiently high that elvers did not respond to fluctuations, and river levels steadily declined, with no fluctuations to respond to.

An increase in American elver migration with increasing river temperatures through most of the run differs from observations by Martin (1995), who noted a temperature effect only during the start of the run and near the end. Sorensen and Bianchini (1986) found no relation between elver movement and river temperature. A preference by European and Japanese elvers for higher water temperatures in long-term experiments (Tongiorgi et al. 1986; Chen and Chen 1991) probably applies to American elvers and would be consistent with the observed temperature effect. No significant effect on the elver run was found for the difference between river and bay water temperature. Neither the hypothesis that elver migration peaks when sea and freshwater temperatures become nearly equal (Gandolfi et al. 1984) nor the conclusion that a high temperature difference between river and bay is preferred by elvers (Marting 1995) are supported by this study.

The collinearity of water temperature and level confounds interpretation of the specific effects of each variable. High water discharge and decreasing temperatures immediately (lag effects of 0 d and 1 d) decreased trap catch. The resultant accumulation and possible draw of elvers to the river from the estuary likely contributed to higher trap catches 4 d later. The 4 d lag of water level accounts for the negative correlation between water level and daily trap count. The statement by Sorensen and Bianchini (1986) that "no study of a location with a well defined interface has shown a correlation between migration and rainfall" appears outdated in light of the results by Martin (1995), who reported a negative effect at the start of the run and a positive effect near the end of the run, and this study, where the relation was positive during the middle of the run, with no relation at the end of the run. An increased effect of olfactory cues, linked to increased discharge, may also influence elver migration via their highly developed olfactory senses (Sorensen 1986; Tosi et al. 1990). When tidal range is small and the river-estuary interface poorly defined, no relation between rainfall (discharge, river height) and elver abundance has usually been found (Jellyman 1977, 1979; Sorensen and Bianchini 1986), although exceptions occur (Jellyman and Ryan 1983).

The difference, in the reduced temperature and temperature difference models, in the dates at which environmental effects became significant may reflect changes over time in the environmental cues guiding elver migration (Martin 1995) or, more likely, be a consequence of model sensitivity. Multiple linear regression models may be quite sensitive to sample sizes (which are small for the first two analysis dates), the variables included, particularly if they are autocorrelated or collinear, and quality and variability of the data (Wilkinson et al. 1996).

Tidal effects on elver migration have been widely observed (Creutzberg 1961; Jellyman 1979; Tesch 1977; McCleave and Kleckner 1982; Gandolfi et al. 1984; Martin 1995) but its importance may be influenced by local hydrographic conditions such as limited tidal range (Jellyman 1977; Sorensen and Bianchini 1986). The strong negative effect of nighttime tidal stage on daily elver count observed in this study contrasts with other North American studies. Sorensen and Bianchini (1986) found no relation between tidal phase and elver migration rate while Martin (1994) concluded that tidal effects were of importance only after about mid-run. The negative, rather than positive, effect results from the lagged effect of tide at the trap sites; nighttime tides 3 d earlier than the count day were declining from a peak 4-5 d earlier. Thus, elvers moved up the estuary with increasing nighttime tide level but entered the stream after a 3 d lag, when nighttime tide levels were decreasing. Elvers moving up the estuary via selective tidal transport, i.e., using semidiurnal vertical migration in phase with the tidal flow to enter the water column while the tidal flow is in the direction of migration and leaving the water column on the ebb flow (McCleave and Kleckner 1982; McCleave and Wippelhauser 1987), also required 1-3 d to move the distance between the fishery site and upstream trap sites. Jellyman (1979) reports a 3-4 d lag between spring tide and migration peak due to the distance between the area where migration begins and catch site. During the first four waves of elver movement, daily trap counts increased concurrently with rising tide for waves 1 and 3 and declined for waves 2 and 4, and three of the four major elver run peaks occurred with tides rising between 1600-2000 h and falling between 2000-2400 h, indicating the crudity of a maximum nighttime tidal measure which does not consider tidal stage (rise, fall) as well as height. The observation by Martin (1995) that the environmental cues influencing elver migration may change in importance during the run is supported by this study and may partly explain the different conclusions reached in studies of similar objective.

Although mean length may increase during the start of the run, both length and weight of American elvers decline slowly throughout the run although the trend may not be so evident in some years and increased growth may be apparent near the end of the run if elvers have resumed feeding, e.g., East River, Sheet Harbour (Jessop, unpublished data). Migratory period length declines have also been reported by Vladykov (1970), and Haro and Krueger (1988) but Hutchison (1981) found little change over two weeks, while weight declines are noted by Groom (1975) and Hutchison (1981). Similar declines in elver length and weight are well documented for the larger European elver (Tesch 1977; Cantrelle 1982). Decreased length during the run results from smaller elvers arriving later in the run (Boëtius 1976; Haro and Krueger 1988) but the weight decline originates in the metabolic use of body energy reserves during completion of metamorphosis from leptocephalus to elver, prior to initiation of feeding (Boëtius 1976). The smaller weight of later arriving elvers may result from beginning metamorphosis further offshore, with consequent greater use of stored energy before estuarial arrival (Jellyman 1977) or simply be determined by leptocephalus size at the start of metamorphosis. The few elvers of high length and weight and low pigmentation at the start of the elver run may derive from unusually large leptocephali.

Elver weight increased curvilinearly with length between 50 and 76 mm, with the relation becoming more curvilinear as growth progresses during the first (Peterson and Martin-Robichaud 1994) and subsequent years (Tesch 1977).

The increase in elver pigmentation over the run reflects an increased degree of completion to the process of metamorphosis from larvae to elver and may generally indicate the amount of time since an elver arrived from offshore (Tesch 1977; Cantrelle 1982). Few glass eels occur by the time elvers enter streams in the northeastern United States and Atlantic Canada (Dutil et al. 1987; Haro and Krueger 1988; this study). The greater pigmentation of later arriving elvers may result from an accelerated pigmentation rate due to seasonally increased estuarial, or even offshore, water temperatures (Strubberg 1913) and a longer post-metamorphic life due to later arriving elvers having begun metamorphosis earlier and further offshore than earlier arriving elvers (Jellyman 1977). Increased pigmentation increases, via protective coloration, the adaptation of elvers to a stream bottom existence.

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References

Anon. 1996. Canadian tide and current tables. Vol. 1. Dept. of Fisheries and Oceans, Ottawa, Ont. 45 p.

Barbin, G. P., and W. H. Krueger. 1994. Behaviour and swimming performance of elvers of the American eel, *Anguilla rostrata*, in an experimental flume. J. Fish Biol. 45: 111-121.

Berg, S., and J. Jørgensen. 1994. Stocking experiments with 0+ eels (*Anguilla anguilla* L.) in Danish streams: post-stocking movements, densities and mortality. p. 314-325. *In* I.G. Cowx (ed.) Rehabilitation of freshwater fisheries. Fishing News Books. London. 486 p.

Boëtius, J. 1976. Elvers, *Anguilla anguilla* and *Anguilla rostrata* from two Danish localities. I. Size, body weight, developmental stage and number of vertebrae related to time of ascent. Medd. Dan. Fisk. Havunders 7: 199-220.

Cantrelle, I. 1982. Étude de la migration et de la pêche de civelles (*Anguilla anguilla* L. 1758) dans l'estuaire de la Gironde. Thèse Doct. 3^e cycle. Univ. Paris VI. 237 p.

Chen, Y.-L., and H.-Y. Chen. 1991. Temperature selections of *Anguilla japonica* (L.) elvers, and their implications for migration. Austr. J. Mar. Freshw. Res. 42: 743-750.

Creutzberg, F. 1961. On the orientation of migrating eels (*Anguilla vulgaris* Turt.) in a tidal area. Neth. J. Sea Res. 1: 257-338.

Deelder, C. L. 1958. On the behavior of elvers (*Anguilla vulgaris* Turt.) migrating from the sea into freshwater. J. Cons. Perm. Int. Explor. Mer. 24: 135-146.

Dutil, J.-D., M. Michaud, and A. Giroux. 1989. Seasonal and diel patterns of stream invasion by American eels (*Anguilla rostrata*) in the northern Gulf of St. Lawrence. Can. J. Zool. 67: 182-188.

Élie, P. 1979. Contribution à l'étude des montées de civelles d'*Anguilla anguilla* Linné dans l'estuaire de La Loire: Pêche, Ecologie, Ecophysiologie et Elevage. Thèse Doct. 3^e cycle. Univ. Rennes. 381 p.

Élie, P., and E. Rochard. 1994. Migration des civelles d'anguilles (*Anguilla anguilla* L.) dans les estuaires, modalités du phénomène et caractéristiques des individus. Bull. Fr. Pêche Piscic. 335: 81-98.

Fahay, M. P. 1978. Biological and fisheries data on American eel *Anguilla rostrata* (LeSueur). U.S. Nat. Oceanic Atmosph. Admin. Northeast Fish. Center Sandy Hook Lab., Tech. Series Rep. No. 17. 77 p.

Gandolfi, G., M. Pesaro, and P. Tongiorgi. 1984. Environmental factors affecting the ascent of elvers, *Anguilla anguilla* (L.) into the Arno River. Oebalia 10: 17-35.

Groom, W. 1975. Elver observations in New Brunswick's Bay of Fundy Region. Res. Develop. Br., N.B. Dept. Fish., Fredericton. 156 p.

Haro, A. J., and W. H. Krueger. 1988. Pigmentation, size and migration of elvers (*Anguilla rostrata* (LeSueur)) in a coastal Rhode Island stream. Can. J. Zool. 66: 2528-25233.

Helfman, G. S., E. L. Bozeman, and E. B. Brothers. 1984. Size, age, and sex of American eels in a Georgia river. Trans. Amer. Fish. Soc. 113: 132-141.

Hilborn, R., and C. J. Walters. 1992. Quantitative fisheries stock assessment. Chapman and Hall, New York. 570 p.

Hutchison, S. J. 1981. Upstream migration of the glass-eel (*Anguilla rostrata*) in Nova Scotia-1981. N.S. Dept. Fish., Man. Tech. Rep. Ser. No. 81-02. 41 p.

Jellyman, D. J. 1977. Invasion of a New Zealand freshwater stream by glass eels of two *Anguilla* spp. N.Z. J. Mar. Freshw. Res. 11: 193-209.

Jellyman, D. J. 1979. Upstream migration of glass-eels (*Anguilla* spp.) in the Waikato River. N.Z. J. Mar. Freshw. Res. 13: 13-22.

Jellyman, D. J., and C. M. Ryan. 1983. Seasonal migration of elvers (*Anguilla* spp.) into Lake Pounui, New Zealand, 1974-1978. N.Z J. Mar. Freshw. Res. 17: 1-15.

Jessop, B. M. 1995. Justification for, and status of American eel elver fisheries in Scotia-Fundy Region. DF0 Atl. Fish. Res. Doc. 95/2. 10 p.

Jessop, B. M. 1996a. Review of the American eel elver fisheries in Scotia-Fundy area, Maritimes Region. DFO Atl. Fish. Res. Doc. 96/04. 7 p.

Jessop, B. M. 1996b. The status of American eels *Anguilla rostrata* in the Scotia-Fundy area of the Maritime Region as indicated by catch and license statistics. DFO Atl. Fish. Res. Doc. 96/ . 15 p.

Jessop, B. M. In review. The management of, and fishery for, American eel elvers in the Maritime Provinces, Canada. Bull. Fr. Pêche Piscic. 000: 000.

Klein Breteler, J. G. P. 1992. Effect of provenance and density on growth and survival of glass eels *Anguilla anguilla* (L.) in mesocosm experiments. p. 15-22 *In* Moriarty, C. (ed.) Irish Fish. Invest., Series A (Freshwater), No. 36. 152 p.

Legault, A. 1988. Le franchissement des barrages par l'escalade de l'anguille étude en Sèvre Niortaise. Bull. Fr. Pêche Piscic. 308: 1-10.

Legault, A. 1994. Étude préliminaire du recrutement fluvial de l'anguille. Bull. Fr. Pêche Piscic. 335: 33-41.

Martin, M. H. 1995. The effects of temperature, river flow, and tidal cycles on the onset of glass eel and elver migration into fresh water in the American eel. J. Fish Biol. 46: 891-902.

McCleave, J. D. 1980. Swimming performance of European eel [*Anguilla anguilla* (L.)] elvers. J. Fish Biol. 16: 445-452.

McCleave, J. D., and R. C. Kleckner. 1982. Selective tidal stream transport in the estuarine migration of glass eels of the American eel (*Anguilla rostrata*). J. Cons. Perm. Int. l'Explor. Mer. 40: 262-271.

McCleave, J. D., and G. S. Wippelhauser. 1987. Behavioral aspects of selective tidal stream transport in juvenile American eels. Amer. Fish. Soc. Symp. 1: 138-150.

Moriarty, C. 1990a. European catches of elver of 1928-1988. Int. Revue. ges. Hydrobiol. 75: 701-706.

Moriarty, C. 1990b. Eel management practice in three lake systems in Ireland. p. 262-269. *In* W. L. T. van Densen, B. Steinmetz, and R. H. Hughes (Eds). Management of freshwater fisheries. Proc. European Inland Fish. Advis. Comm., Göteborg, Sweden, 1988. Pudoc. Wageningen.

Moriarty, C. 1992. Catches of *Anguilla anguilla* elver on the Atlantic coast of Europe 1989-1990. p. 33-34. *In* Moriarty, C. (ed.) Irish Fish. Invest. Series A (Freshwater), No. 36. 152 p.

Moriarty, C., M. Bninska, and M. Leopold. 1990. Eels, *Anguilla anguilla* L., stock and yield in Polish lakes. Aquacult. Fish. Mgmt 21: 347-355.

O'Leary, D. 1971. A low head elver trap developed for use in Irish rivers. EIFAC Tech. Pap. 14: 129-142.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Bd. Canada, Bull. 191. 382 p.

Sorensen, P. W. 1986. Origins of the freshwater attractant(s) of migrating elvers of the American eel *Anguilla rostrata*. Env. Biol. Fishes 17: 185-200.

Sorensen, P. W., and M. L. Bianchini. 1986. Environmental correlates of the freshwater migration of elvers of the American eel in a Rhode Island brook. Trans. Amer. Fish. Soc. 115: 258-268.

Smith, M. W. 1955. Control of eels in a lake by preventing the entrance of young. Can. Fish Cult. 17: 13-17.

Strubberg, A. C. 1913. The metamorphosis of elvers as influenced by outward conditions. Medd. Komm. Havunders. Ser. Fisk. 4: 1-11.

Tesch, F.-W. 1977. The eel: biology and management of Anguillid eels. Chapman and Hall, London. 434 p.

Tongiorgi, P., L. Tosi, and M. Balsamo. 1986. Thermal preferences in upstream migrating glass-eels of *Anguilla anguilla* (L.). J. Fish Biol. 28: 501-510.

Tosi, L., A. Spampanato, C. Sola, and P. Tongiorgi. 1990. Relation of water odour, salinity and temperature to ascent of glass-eels, *Anguilla anguilla* (L.): a laboratory study. J. Fish Biol. 36: 327-340.

Vøllestad, L. A., and B. Jonsson. 1988. A 13-year study of the population dynamics and growth of the European eel *Anguilla anguilla* in a Norwegian river: evidence for density-dependent mortality, and developement of a model for predicting yield. J. Anim. Ecol. 57: 983-997.

Walsh, P. J., G. D. Foster, and T. C. Moon. 1983. The effects of temperature on the metabolism of the American eel *Anguilla rostrata* (LeSueur): compensation in the summer and torpor in the winter. Physiol. Zool. 56: 532-540.

Watt, W. D. 1986. The case for liming some Nova Scotia salmon rivers. Water, Air, and Soil Pollution 31: 775-789.

Watt, W. D., and W. J. White. 1992. Creating a de-acidified Atlantic salmon refuge in East River, Nova Scotia. Report for 1991 from the Atlantic Region Monitoring and Effects Working Group, p. 148-164. Billie L. Beattie ed. Envir. Can., Bedford, N.S. 194 p.

Watt, W. D., C. D. Scott, and P. Mandell. 1995. Water chemistry data from a monitoring program designed to detect changes in the long range transport of acidic pollutants into Nova Scotia's acidified Atlantic Salmon rivers. Can. Data Rep. Fish. Aquat. Sci. No. 972. 103 p.

Wilkinson, L., G. Blank, and C. Gruber. 1996. Desktop data analysis with SYSTAT. Prentice Hall, NJ. 798 p.

Appendix 1.

Between May 23 and June 1, a total of 40,650 elvers were marked by immersion for 24 h in a 100 ppm solution of alizarin complexone, a dye that stains otoliths with a fluorescent mark (Beckman and Schulz 1996). The daily releases of marked elvers were: May 24 - 9,980, May 25 - 9,980, May 29 - 10,050, and June 1 - 10,640. A total of 191 elvers died before release.

The elver marking was planned with the intent that marked eels would be recoverable within two years (the duration of mark detectability) by the annual electrofishing program carried out by DFO on the East River, Chester as part of a study of the benefits of headwater liming for enhancing salmon production in low pH waters. The distribution and size of marked eels within the river could provide insight into rates of movement, growth, and mortality. However, the DFO liming project and associated electrofishing has been cancelled due to budget reductions and staff reorganization.

Beckman, D. W., and R. G. Schulz. 1996. A simple method for marking fish otoliths with alizarin compounds. Trans. Amer.Fish. Soc. 125: 146-149.

Table 1. Estimated[a] trap and commercial fishery dipnet catches of American eel elvers, by date, from the East River, Chester, 1996.

Date	Trap Number				Catch		
	1	2	3	4	Total	Juvenile	Fishery
April 27	-	-	-	-	-	-	9,160
April 28	-	-	-	-	-	-	0
April 29	-	-	-	-	-	-	12,280
April 30	-	-	-	-	-		0
May 1	-	-	-	-	-	-	0
May 2	-	-	-	-	-	-	0
May 3	-	-	-	-	-	-	-
May 4	-	-	-	-	-	-	-
May 5	0	810	0	0	810	0	-
May 6	0	30	0	0	30	0	-
May 7	0	0	0	0	0	0	-
May 8	0	3	0	1	4	0	0
May 9	0	0	0	3	3	0	-
May 10	0	0	0	11	11	0	-
May 11	0	0	0	0	0	0	0
May 12	0	0	0	0	0	0	-
May 13	0	0	0	0	0	0	-
May 14	0	1	0	2	2	0	-
May 15	0	0	0	0	0	0	7,280
May 16	0	52	0	5	57	0	19,640
May 17	2,440	12,080	0	200	14,720	0	11,600
May 18	690	10,730	9,130	9,530	30,080	32	6,330
May 19	54	1,940	2,210	810	5,020	0	1,820
May 20	38	1,110	1,750	40	2,940	12	0
May 21	0	14	250	27	290	0	9,600
May 22	800	4,030	2,830	61	7,720	11	19,580
May 23	3,610	13,880	21,260	1,730	40,480	38	8,650
May 24	10,220	26,610	26,580	3,820	67,220	45	8,380
May 25	27,520	49,040	6,980	6,680	90,220	44	2,900
May 26	9,030	17,920	11,480	5,740	44,170	24	-
May 27	6,760	7,820	7,400	12,060	34,040	22	-
May 28	5,780	10,210	4,300	360	20,650	15	-
May 29	23,850	650	310	1,450	26,260	9	-
May 30	7,130	200	650	220	8,200	3	0
May 31	610	1,820	1,170	41	3,640	7	-
June 1	280	910	770	8	1,570	1	36,630
June 2	17,320	42,320	18,560	740	79,240	43	42,770
June 3	18,650	36,360	27,860	5,520	88,390	17	40,730
June 4	7,050	17,860	14,570	4,440	43,920	21	21,470
June 5	420	550	2,710	440	4,120	12	-
June 6	1,000	210	440	270	1,920	7	15,000
June 7	3,450	830	1,290	2,000	7,570	10	20,780
June 8	6,780	5,050	5,180	15,820	32,830	13	7,700
June 9	16,130	1,340	13,980	20,160	51,610	20	6,000
June 10	4,840	76	2,680	4,740	12,340	29	9,620
June 11	2,460	150	940	440	3,990	7	3,850
June 12	4,650	610	560	920	6,740	25	-
June 13	4,590	340	2,690	570	8,190	23	-
June 14	6,360	1,250	4,950	210	12,770	37	-
June 15	4,510	610	2,630	210	7,960	31	-
June 16	4,110	420	1,860	240	6,630	25	6,110
June 17	3,560	1,860	3,210	53	8,680	38	-
June 18	100	860	1,710	77	2,750	13	2,040
June 19	270	340	1,420	440	2,470	12	-
June 20	250	58	1,310	44	1,660	5	1,140
June 21	190	9	1,060	26	1,280	9	-
June 22	28	1	580	31	640	12	-
June 23	18	21	230	11	280	4	-
June 24	94	17	1,350	124	1,580	21	-
June 25	27	35	1,240	32	1,330	12	-
June 26	34	12	340	42	430	5	-
June 27	20	25	650	3	700	7	-
June 28	24	125	510	2	660	4	-
June 29	-	53	810	2	860	4	-
June 30	57	71	670	2	800	13	-
July 1	88	19	120	2	220	2	-
July 2	93	46	76	4	220	0	-
July 3	84	0	108	1	190	2	-
July 4	110	0	16	1	127	2	-
July 5	58	16	79	23	176	1	-
July 6	42	21	50	3	116	2	-
July 7	54	119	46	9	230	1	-
July 8	6	18	5	1	30	1	-
July 9	8	38	7	11	64	3	-
July 10	10	35	10	10	65	0	-
July 11	5	44	8	33	90	3	-
July 12	5	85	43	6	139	12	-
Total	206,650	271,790	213,610	100,540	792,590	771	331,060

[a] Estimates are rounded to nearest 10 elvers; values less than 150 are exact.

Table 2. *t*-Values and their significance, adjusted multiple R^2 values and regression significance for parameters of the multiple regression model (1)
$E = B_0 + B_1 T + B_2 H + B_3 M$[a]

	t-Values (Probability)				
Date	River temperature	River height	Tide height	R^2	P
May 18	3.01 (0.06)	-1.87 (0.16)	-3.03 (0.06)	0.66	0.11
May 25	1.49 (0.17)	0.93 (0.37)	-1.47 (0.17)	0.40	0.045
June 3	2.38 (0.03)	1.01 (0.32)	-3.26 (0.004)	0.48	0.001
June 11	2.76 (0.01)	1.13 (0.27)	-3.07 (0.005)	0.42	0.001
June 12-July 12	0.98 (0.34)	-1.01 (0.32)	-0.05 (0.96)	0.0	0.55

[a] E = daily elver trap total count; B_0 = intercept; B_i = coefficient for each parameter; T = daily mean river water temperature; H = daily river guage height (level); M = maximum tide height for the night preceding the elver count.

Table 3. *t*-Values and their significance, adjusted multiple R^2 values and regression significance for parameters of the multiple regression model (1a)
$E = B_0 + B_1 T + B_2 M$[a]

	t-Values (Probability)			
Date	River temperature	Tide height	R^2	P
May 18	1.81 (0.10)	-2.20 (0.05)	0.30	0.066
May 25	2.24 (0.04)	-2.32 (0.03)	0.31	0.017
June 3	3.25 (0.003)	-3.15 (0.004)	0.38	0.001
June 11	3.73 (0.001)	-3.27 (0.003)	0.37	0.0001
June 12-July 12	0.98 (0.34)	-0.05 (0.96)	0.0	0.55

[a] E = daily elver trap total count; B_0 = intercept; B_i = coefficient for each parameter; T = daily mean river water temperature; M = maximum tide height for the night preceding the elver count.

Table 4. *t*-Values and their significance, adjusted multiple R^2 values and regression significance for parameters of the multiple regression model (2)
$E = B_0 + B_1 (\Delta T) + B_2 H + B_3 M$[a]

	t-Values (Probability)				
Date	Temperature difference	River height	Tide height	R^2	P
May 18	1.44 (0.25)	-0.90 (0.43)	-1.58 (0.22)	0.20	0.38
May 25	1.07 (0.31)	1.11 (0.29)	-1.35 (0.21)	0.34	0.07
June 3	0.97 (0.34)	2.24 (0.04)	-2.59 (0.02)	0.36	0.001
June 11	0.87 (0.39)	2.45 (0.02)	-2.52 (0.02)	0.28	0.008
June 12-July 12	0.77 (0.45)	-1.07 (0.30)	-0.16 (0.87)	0.0	0.63

[a] E = daily elver trap total count; B_0 = intercept; B_i = coefficient for each parameter; ΔT = difference between daily mean river and bay water temperatures; H = daily river guage height (level); M = maximum tide height for the night preceding the elver count.

Table 5. *t*-Values and their significance, adjusted multiple R^2 values and regression significance for parameters of the multiple regression model (2a)
$E = B_0 + B_1 H + B_2 M$[a]

	t-Values (Probability)			
Date	River height	Tide height	R^2	P
May 18	0.19 (0.86)	-0.77 (0482)	0.0	0.46
May 25	1.83 (0.9)	-1.05 (0.32)	0.33	0.044
June 3	2.57 (0.02)	-2.68 (0.01)	0.36	0.005
June 11	2.61 (0.01)	-2.50 (0.02)	0.29	0.003
June 12-July 12	-1.08 (0.29)	-0.13 (0.90)	0.0	0.56

[a] E = daily elver trap total count; B_0 = intercept; B_i = coefficient for each parameter; H = daily river guage height (level); M = maximum tide height for the night preceding the elver count.

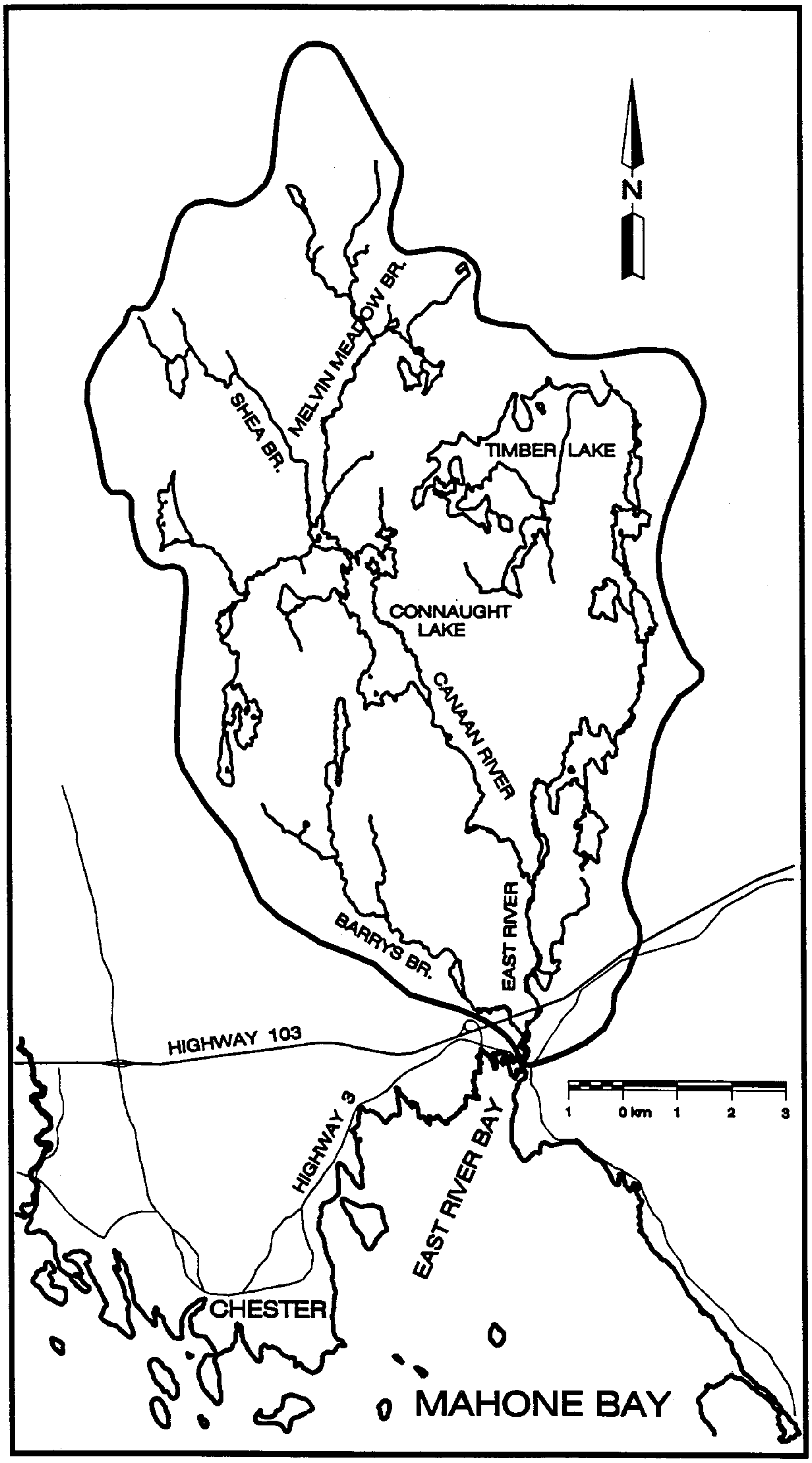

Figure 1. Drainage basin of the East River, Chester (area 134.0 km^2).

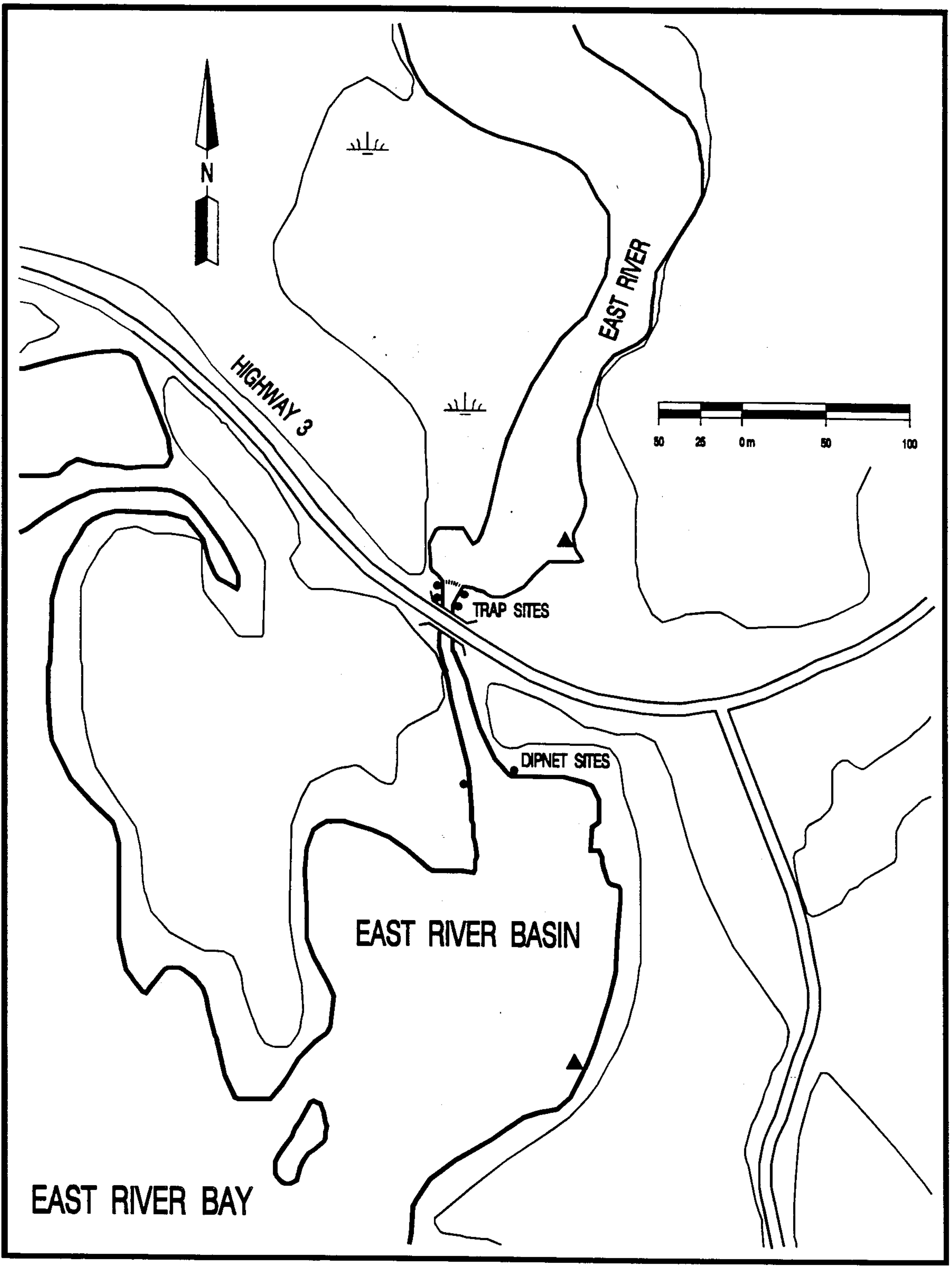

Figure 2. Elver trap locations on the East River, Chester. Solid triangles indicate thermograph sites.

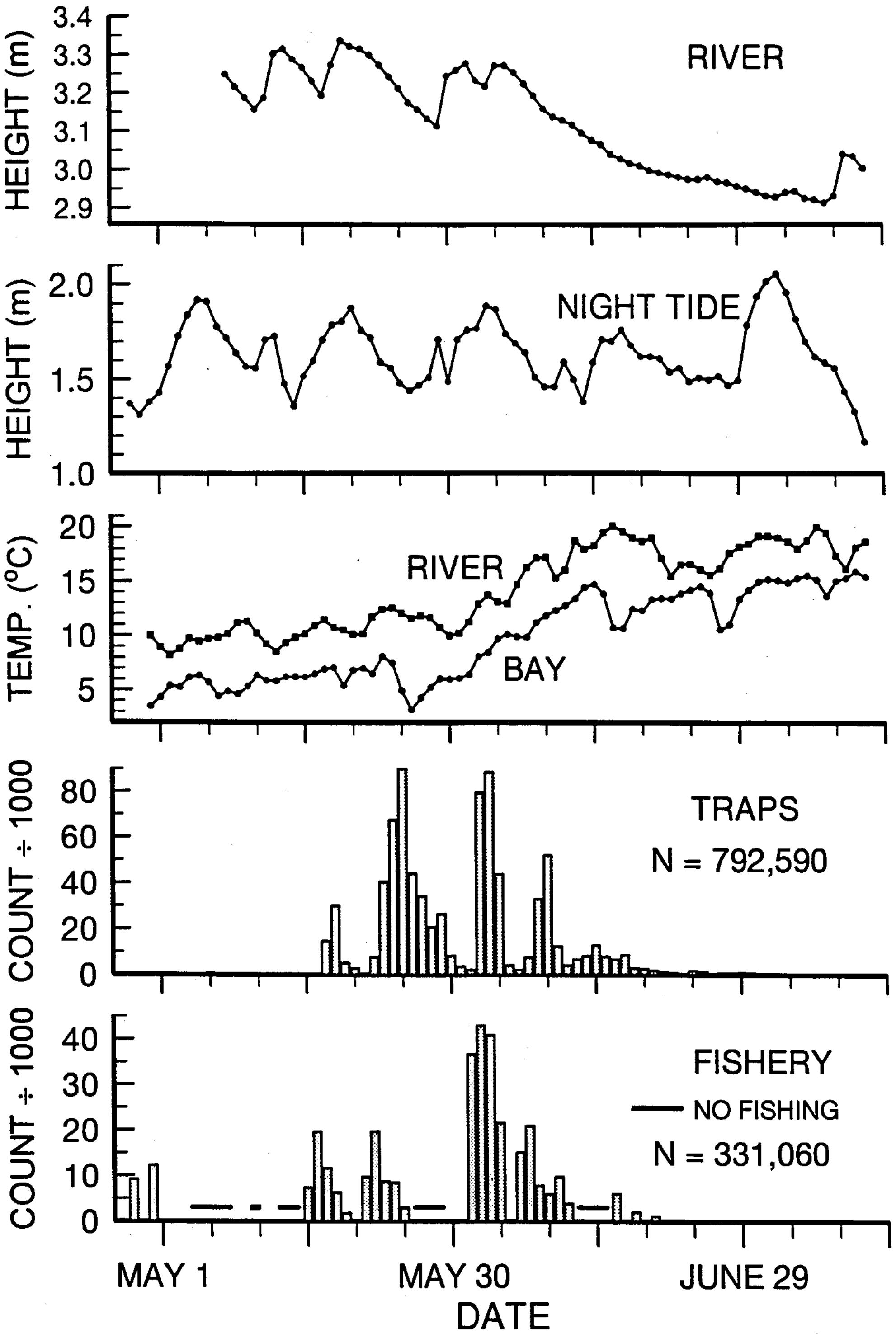

Figure 3. Daily river water levels, nighttime tide heights, river and bay water temperatures, elver trap counts, and dipnet fishery catches for the East River, Chester, 1996.

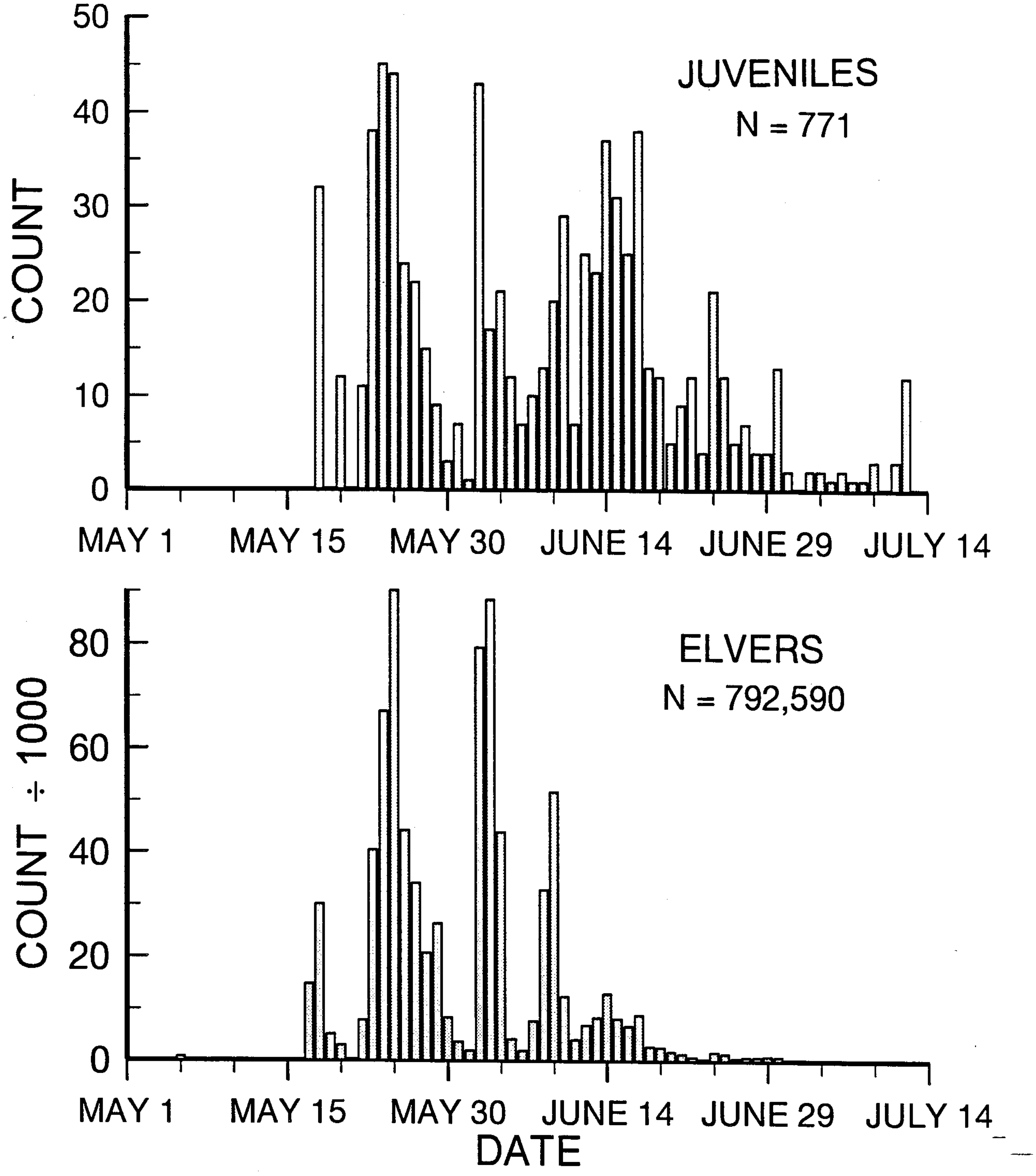

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Figure 4. Daily counts of elver and juvenile American eels from the East River, Chester, 1996.

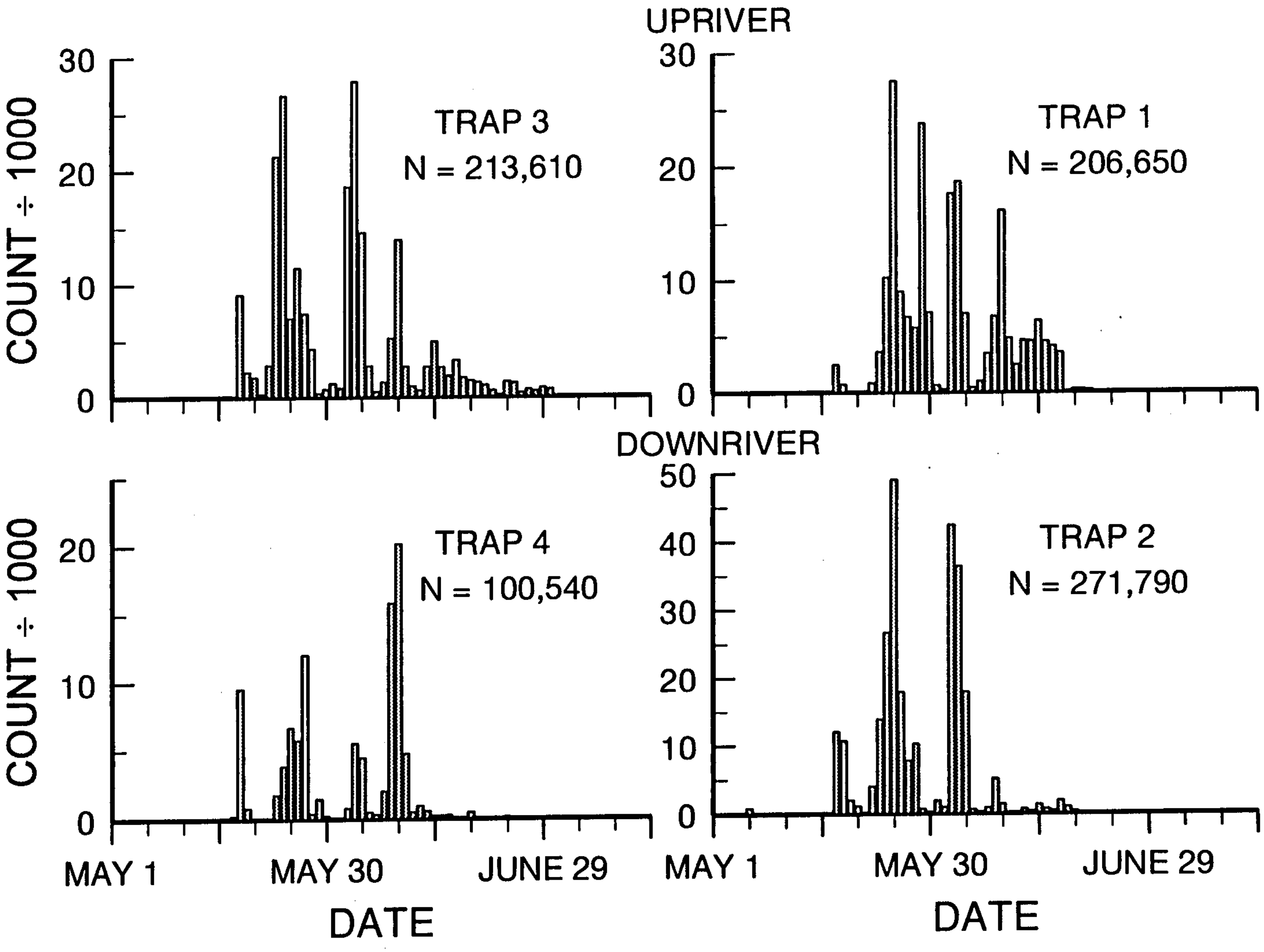

Figure 5. Daily counts of American eel elvers, by trap, from the East River, Chester, 1996. Traps 1 and 2 were sited on the true right bank, traps 3 and 4 on the left bank.

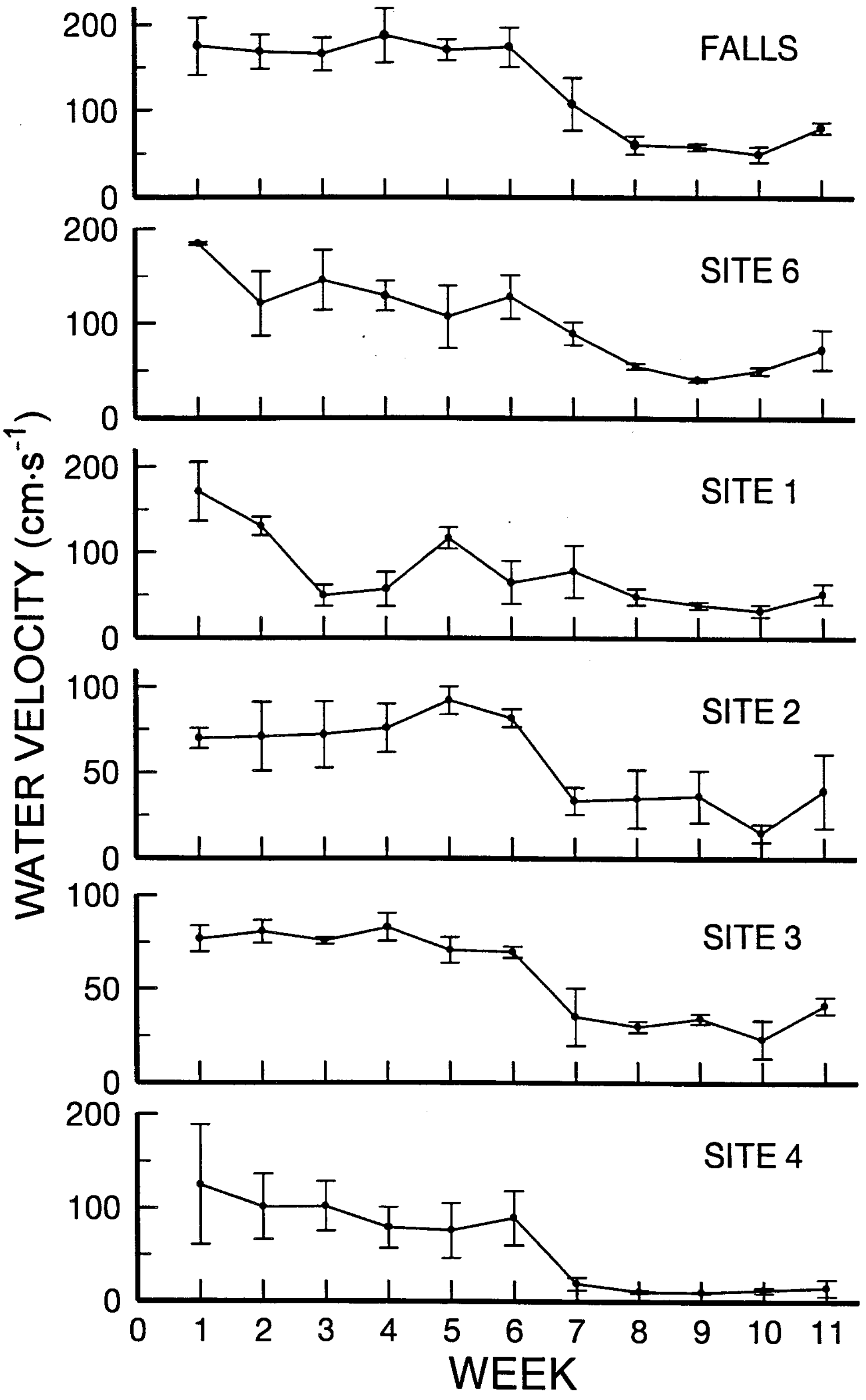

Figure 6. Mean (± 1 SE) water velocity, by site and week, for the East River, Chester, Weeks (in brackets): May 1-7 (1), May 8-14 (2), May 15-21 (3), May 22-28 (4), May 29-June 4 (5), June 5-11 (6), June 12-18 (7), June 19-25 (8), June 26-July 2 (9), July 3-9 (10), July 10-16 (11).

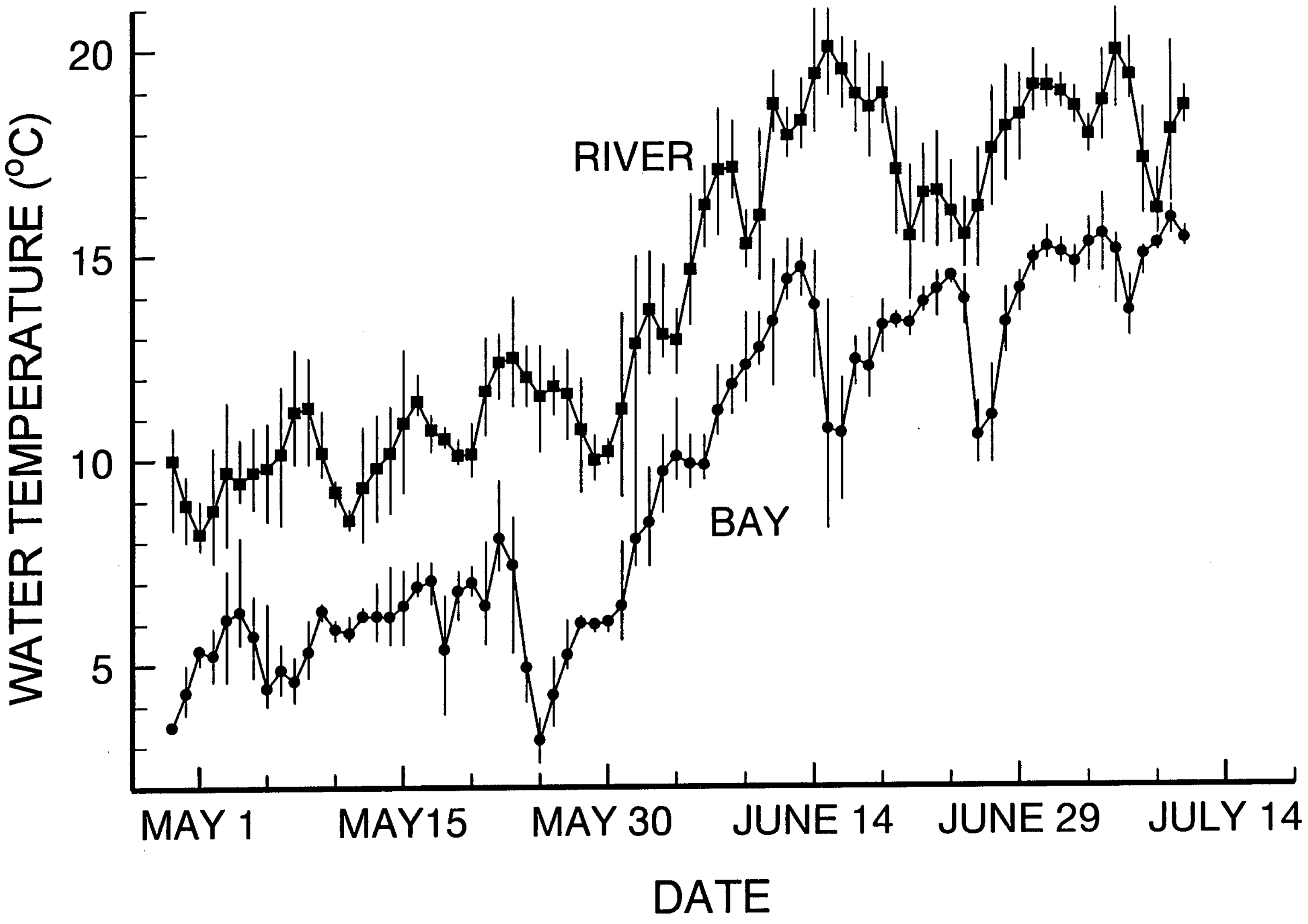

Figure 7. Daily mean and range of water temperatures from the East River, Chester and East River Bay, 1996.

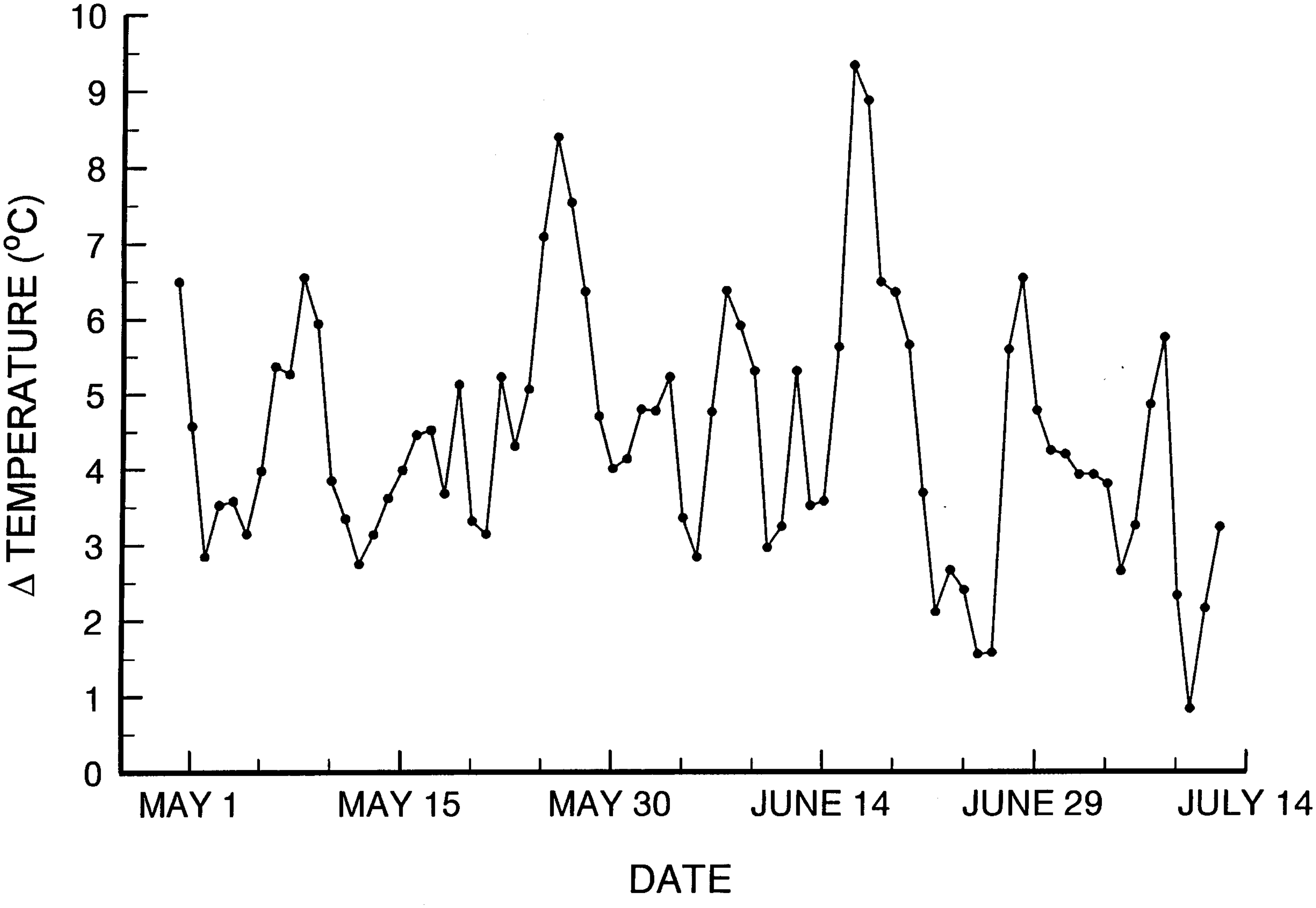

Figure 8. Difference in daily water temperatures between the East River, Chester and East River Basin, 1996.

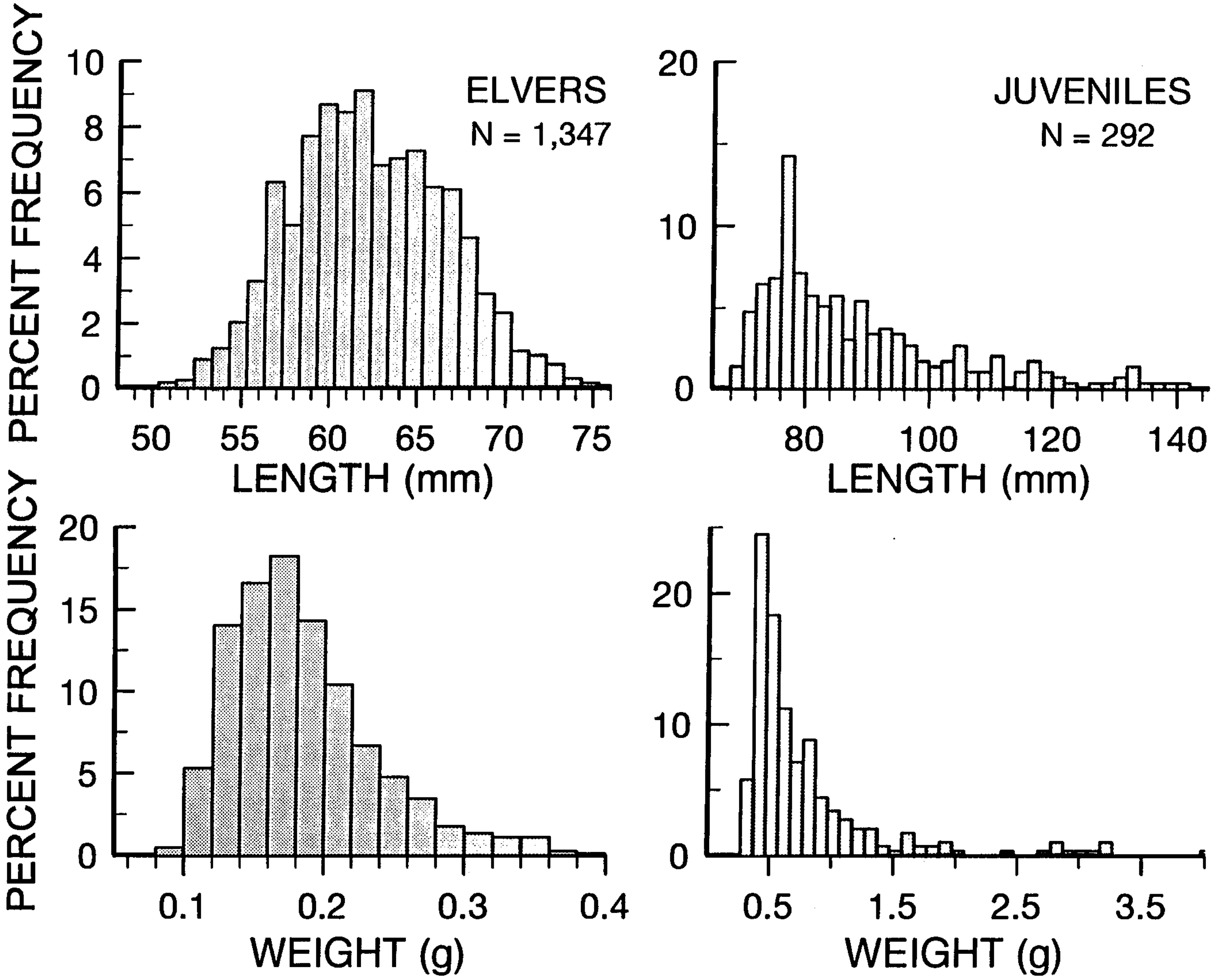

Figure 9. Total lengths and weights of elvers and juvenile American eels from the East River, Chester, 1996.

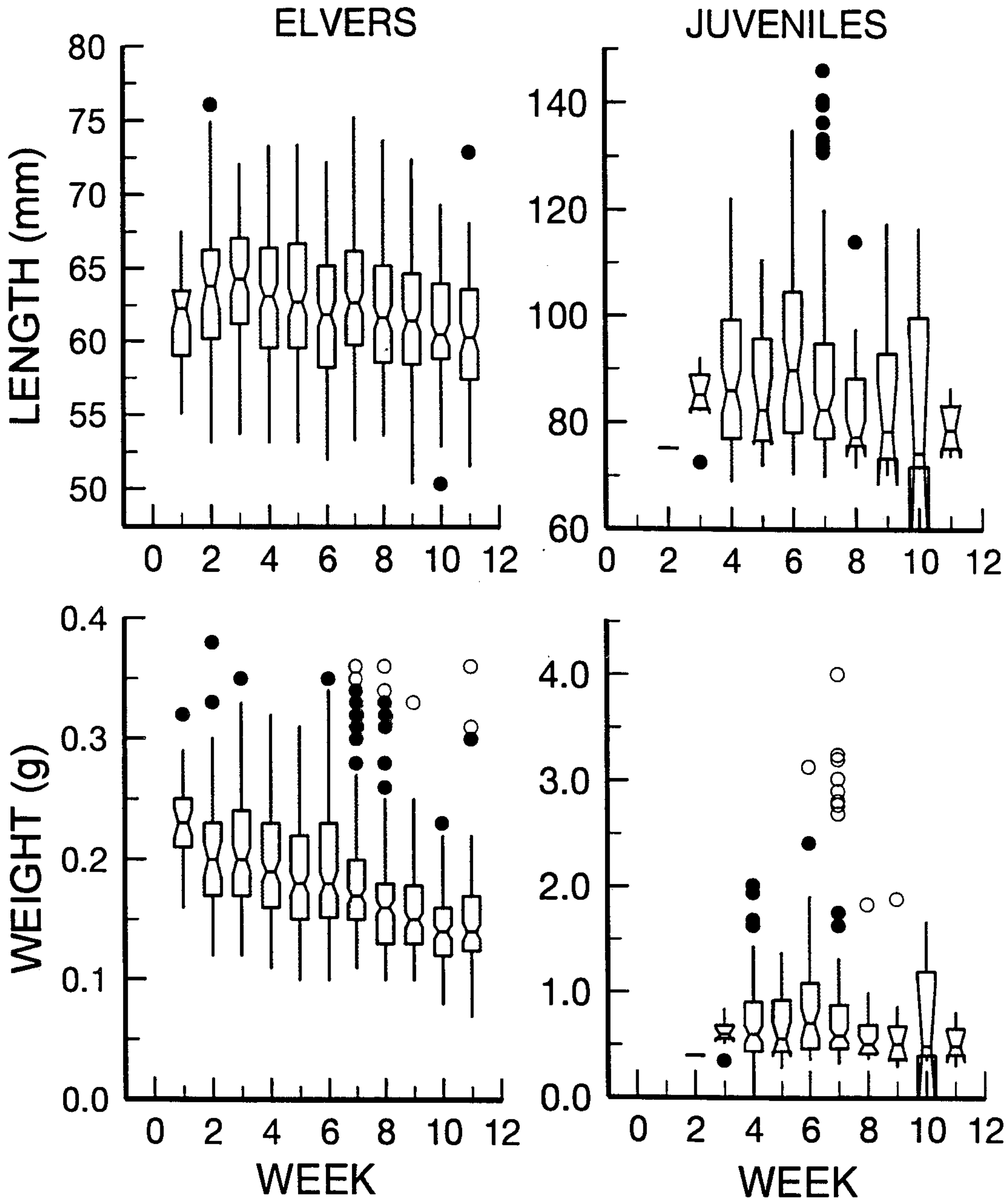

Figure 10. Median and sample distribution of lengths and weights of elvers and juvenile American eels, by week, from the East River, Chester, 1996. The center of the horizontal line marks the median of the sample distribution, the limits of the notches approximate a 95% CI about the median, the box limits (hinge values) represent the central 50% of the data range, the whiskers mark the range of values 1.5X hinge, and the solid and open dots represent outside and far outside values. Sample sizes, by week (in parentheses), for elvers and juveniles, respectively, were: (1) 30, 0, (2) 41, 1, (3) 102, 9, (4) 152, 74, (5) 160, 23, (6) 55, 45, (7) 165, 5, (8) 157, 34, (9)151, 10, (10) 130, 4, (11) 104, 7. Weeks: May 1-7 (1), May 8-14 (2), May 15-21 (3), May 22-28 (4), May 29-June 4 (5), June 5-11 (6), June 12-18 (7), June 19-25 (8), June 26-July 2 (9), July 3-9 (10), July 10-16 (11).

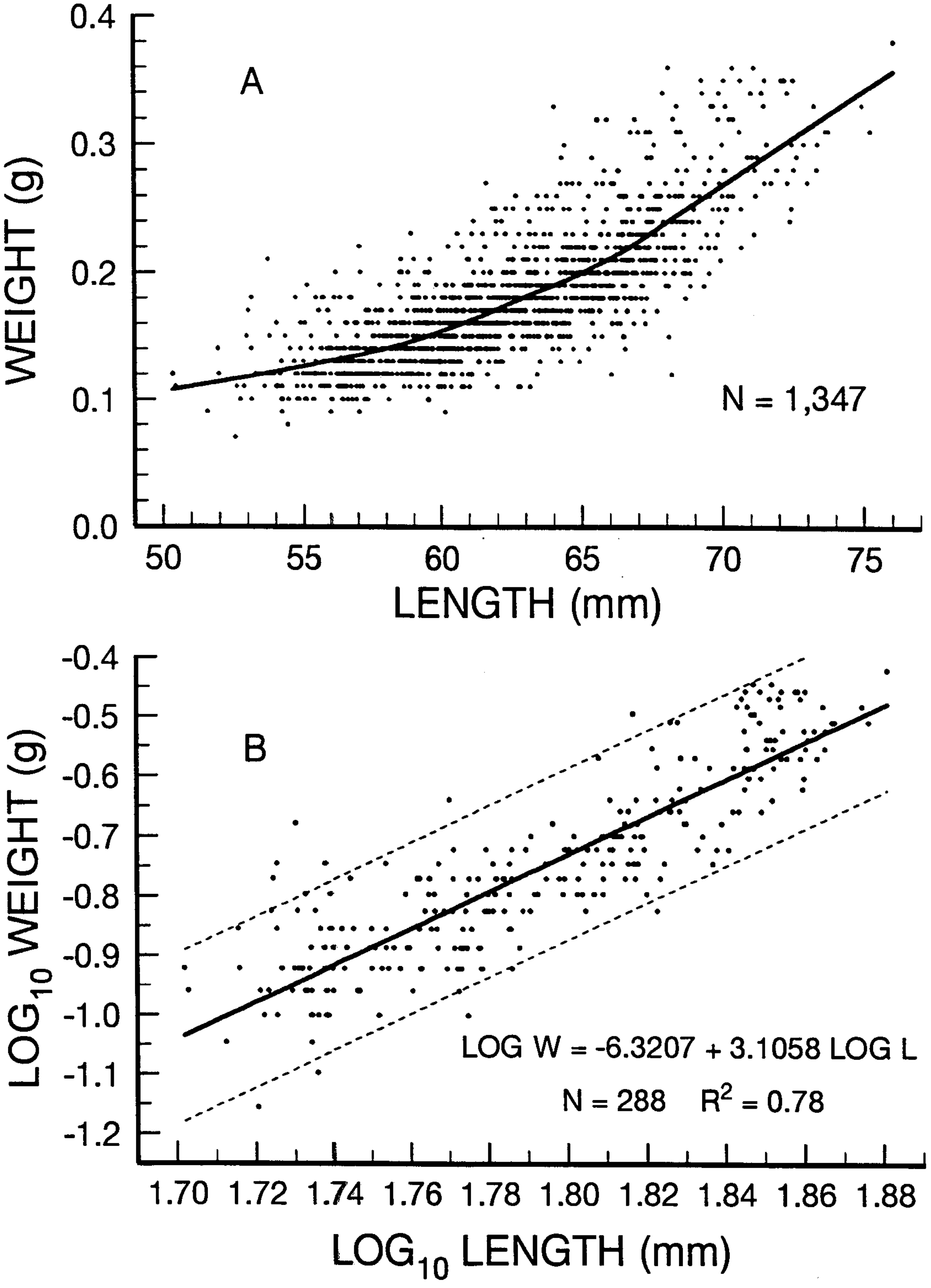

Figure 11. Weight-length distribution of (A) the observed data and (B) logarithmically transformed values of a randomly selected subset of the data, with linear regression equation and 95% confidence limits, for American eel elvers from the East River, Chester, 1996.

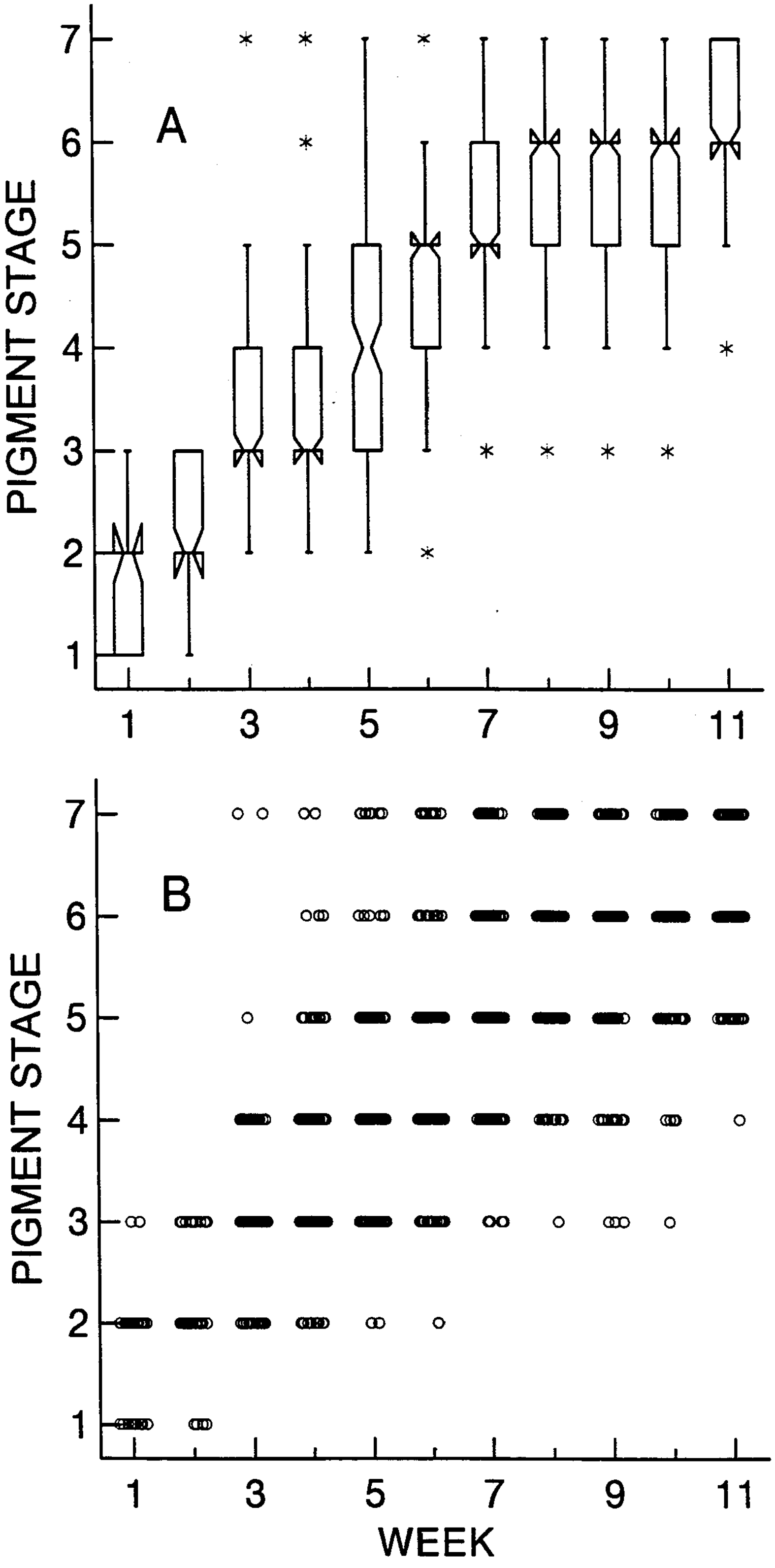

Figure 12. Median and sample distribution (A) and sample density distribution (B), by week, of the pigment stage of American eel elvers from the East River, Chester, 1996.