The Biological Characteristics of, and Efficiency of Dip-net Fishing for, American Eel Elvers in the East River, Chester, Nova Scotia 1997

by

B. M. Jessop
Department of Fisheries and Oceans
P. O. Box 550
Halifax, Nova Scotia
B3J 2S7

Doc. No 98- 01 February 1998

Report of the Joint Project Agreement for Study of the Elver Fishery F289-5-0418
Department of Fisheries and Oceans
Halifax, Nova Scotia

Abstract

In 1997, American eel elvers were first caught in the estuary of the East River, Chester, on May 11 when estuarine water temperatures were about 6 °C and river temperatures were about 7 °C. The catches from a commercial dip-net fishery for elvers and from four elver traps situated just downstream of a natural falls were used to estimate the escapement from the fishery, total run size and, fishery exploitation rate. About 463,300 elvers were caught by the dip-net fishery between May 11 and June 12 while 1,018,620 elvers were caught in the elver traps between May 22 and July 15. The total run was estimated at 1,481,900 (95% CI ± 91,800) elvers and the fishery exploitation rate at 31.3% (95% CI 27.5% - 35.5%).

Elver daily run size was uninfluenced by river water temperature, the difference between river and estuarine water temperatures, or nightime tide height but tended to decrease with increasing river water level. The effect of various environmental variables differed in 1997 from their effect in 1996, indicating that annual conditions play an important role in regulating the upstream movement of elvers. Elver lengths decreased by 8%, weight by 41%, and pigmentation stage progressed from none (glass eel) to fully pigmented as the run progressed.

The growth of the fishery for American eel (*Anguilla rostrata*) elvers in the Scotia-Fundy area of the Maritime Provinces has been tightly controlled with the intent of ensuring that, in conjunction with moderate controls for existing fisheries for larger eels, overexploitation of the eel resource does not occur either in specific rivers or regionally, with possible negative effects on the continental stock (Jessop 1995; 1996a; 1996b). Numerous aspects of the biology of American eels are unknown or uncertain, including the intensity of elver fishing tolerable without major effect on the abundance of larger eels in a river and the capture efficiency of commonly used fishing gears. This report analyzes the results of the 1997 study on the East River, Chester, Nova Scotia examining: 1. the efficiency (catch per hour of fishing effort) of the dip-net commonly employed in the local elver fishery, 2. the rate of exploitation (catch as a proportion of the total elver run) by such a fishery, 3. the seasonal duration, daily abundance, and size of the elver run, and 4. the seasonal composition of elver length, weight, and pigmentation stage. The format of the 1996 report (Jessop 1996) is followed so as to facilitate comparison of the characteristics of the elver runs in 1996 and 1997 to the East River, Chester.

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) 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) joins 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. The river habitat is suitable for Atlantic salmon (*Salmo salar*) but acidification impairs water quality such that it is judged a Category 2 river (pH range 4.7-5.0) with only a remnant population surviving in tributaries with higher pH (Watt 1986). River pH 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. The Canaan River tributary is acidified, with annual pH values averaging 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 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 and densities of salmon parr and juveniles increased substantially.

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

The elevation 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-like widening of the river and the head of tide just upriver of the Highway 3 bridge (Figure 2). Most (about 0.6 m) of the vertical drop occurs at the waterfall or within 2-3 m of it. The presence of rapids at the mouth of the river was a major factor in the selection of this river as the project site because of the presumed velocity barrier to elver movement upstream extending across the river width created by the relatively high discharge occurring throughout the run.

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 head of tide. The traps were numbered as follows: 1. furthest downstream on true (proceeding downstream) right bank, 2. upstream on true right bank, 3. downstream on true left bank, and 4. upstream on true left bank.

Trap sites were selected with the objective of collecting all elvers migrating upstream, with the expectation that the water velocities and vertical drops across the fall line between pond and outlet stream would prevent upstream movement except when water velocities declined with seasonally reducing discharge and where elvers could find a convenient, near-shore path around the main stream obstacles, perhaps provided by lower velocity, near-shore flows or damp, on-shore pathways. 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, with counts of individual elvers when numbers were small or by volumetric estimation in approximately 50 ml aliquots by calibrated graduated cylinder. An additional count was made, as necesssary, near midnight during run peaks. Over a period of several days ending on 6 June and on 24 June (early and mid-run), up to nine calibration counts were made at each of three volumes (50, 75, 100 ml) and the mean elver counts at a volume of 50 ml (early run: 190 elvers, SD = 17.01; late run: 270 elvers, SD = 12.82; N = 9 in both samples) were used as the calibration constants for the appropriate run periods. Early and late run mean elver counts at 50 ml differed significantly ($F_{1,16} = 127.0$, $P < 0.0001$). The linear regression relating elver count (Y) with cylinder volume (X) for the early run period was $Y = 4.487X - 30.204$ (N = 27, $r^2_{adj} = 0.94$, $P < 0.0001$) and for the late run period was $Y = 5.218X + 9.824$ (N = 15, $r^2_{adj} = 0.99$, $P < 0.0001$).

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.

All elvers not sampled for biological data were released alive upriver about 75 m from the falls at the river mouth. Juvenile eels (fully pigmented, sizes exceeding 0.75 mm and 0.35 g) 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. 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, sampled eels were categorized as elver if the following criteria were met: 1. any size, and pigmentation stage ≤ 5 (following the pigmentation stage classification of Haro and Krueger (1988)); 2. size ≤ 70 mm and 0.30 g, and pigmentation up to stage 7 before June 1; 3. size ≤ 75 mm and 0.35 g, and pigmentation up to stage 7 between June 1 and July 15. Eels were categorized as juvenile (age 1 and older) if they: 1. were fully pigmented (pigment stage 8, equivalent to stage VII of Elie et al. (1982)), or 2. exceeded the sizes defining age 0 elvers. 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). Twenty-two eels were reclassified as to elver or juvenile, typically from putative juvenile to elver, or about 1.5% of all sampled eels (*N* = 1,437). Most reclassified eels were of pigment stage 7 and small size and occurred early in the run when other elvers were of low pigmentation stage.

Water temperatures (to 0.1 °C) were recorded every two hours by thermographs set in the East River upriver (50 m) of the falls and at a wharf in the estuary about 0.5 km from the river mouth (Figure 2). 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 1 and by a Global Water (11257 Coloma Rd., Gold River, CA 95670) WL-3 water level logger (to ± 0.2 cm) installed on May 27. 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. 1997). Hourly tidal measurements were also obtained from a Global Water WL-14 water level logger (to ± 0.8 cm) placed in the estuary on 17 April at the thermograph site. All water level and temperature recorders were removed on July 15.

Near-shore (about 15 cm from shore and 10 cm below the surface) water velocities were measured with a Global Water FP100 flow probe (to ± 0.03 $m \cdot s^{-1}$) 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 ($N = 32$, $r = 0.65$, $P = 0.0001$) between daily mean water velocity ($m \cdot s^{-1}$) and water level (m) was estimated after both variables were detrended of seasonal decline effects by differencing (subtracting the previous value for each case from the current value; 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 aperture = 1 mm^2) for elvers was conducted in a standardized 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 h) were recorded in a fishery logbook. Dip-net fishing efficiency or exploitation rate (ER) was calculated as ER(%) = 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. The "dry weight" correction factor was estimated at 21.4% ± 3.6% (95% CI) in 1997 by repeated (three) weighings of about 1 kg of elvers using the procedures followed by elver fishers followed by additional drying to estimate the amount of retained water. The 21.4% value is probably biased low (the first estimate was 24.5%, the final estimate 18.3%) because of a gain in weight by elvers when repeatedly immersed in water while progressively being stripped of their protective coating of slime by the soaking and drying process. Thus, the 25% correction factor used by commercial fishers is reasonable and was used in this report for consistency. The 95% confidence interval of ± 3.6% was applied to the 25% correction factor. 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 (1996) or July 15 (1997), whichever came first.

The upstream movement of elvers was assessed by placing elver tube traps (a 1 m length of 15 cm diameter perforated polyethylene piping, sealed at the upstream end by a 0.5 mm square mesh and filled with a roll of Enkamat open-weave polyethylene matting to provide a substrate for elvers) at four progressively upstream locations (Figure 3). Site A was located at the head of the pond, about 0.5 km upstream from the falls at the river mouth and entrance to the pond; Site B was located about 0.29 km upstream of Site A on the main stem of the river; Site D was located 0.58 km upstream of Site B and 1.37 km from the river mouth; Site C was located on the Barry's Brook tributary 0.58 km upstream of Site A and 1.08 km from the river mouth. Sites C and D were initially positioned at the downstream side of the Highway 103 culvert but on July 4 were repositioned upstream of the culvert because elvers were observed in the culverts. At each site, a single tube trap was positioned close to the bank with the open end facing downstream and with a flow of water through the trap. Sites A and B were checked daily after trap installation on May 23 while Sites C and D were checked less frequently. Catches were counted and a sample of up to 30 elvers taken for measurement of length and weight and evaluation of pigmentation stage.

The gradient between the falls at the river mouth and Site A is essentially flat (a pond) while from Site A to Site B is largely pond with a small stream section. The sections between Site A and C and D are largely stream with variable gradient. Thus, from the river mouth to Site D on the main stem, the gradient averaged 1.3%, with a 70 m section near Site D of 7.6% gradient while from river mouth to Site C on Barry's Brook the gradient averaged 0.9% with a maximum gradient of 4.4% over an 80 m section near Site C.

The effects of environmental variables on the start and pattern of elver migration and on the dip-net fishery 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 or dip-net fishery catch; 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 both the daily elver count and the dip-net catch were influenced by the difference between river and estuarine (bay) water temperatures, 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:

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

Model 1 will be termed the river temperature model and model 2 the temperature difference model hereafter.

Spurious or inflated correlations between the daily elver count and each environmental variable and between environmental variables, e.g., due to the seasonal trends such as an increase in river water temperatures and decline in water levels ($r = -0.90$, $P < 0.001$, $N = 76$) were avoided by differencing each 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). After differencing, the negative correlation between river water level and temperature remained significant ($r = -0.31$, $P = 0.006$, $N = 75$).

Correlations between differenced values of the daily elver count (logarithmically (base 10) transformed to reduce the non-normality of the distribution of counts) and each environmental variable, and between 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 or on another environmental variable. The temperature difference between river and bay was significantly correlated with river temperature ($r = 0.49$, $P < 0.0001$, $N = 75$), after reducing autocorrelation in and detrending both variables by differencing. The river-bay temperature difference was also significantly correlated with night tide height ($r = 0.31$, $P = 0.007$, $N = 75$) after differencing and removing the significant two day lag effect (correlation between ΔT and night tide height two days previously). No lag adjustments were necessary between elver counts and any environmental variable. Differenced and appropriately lagged river level and temperature, river-bay temperature difference, and night tide values were used in the multiple linear regressions of elver counts with environmental variables.

Uncertainty exists as to whether linear or multiple linear regressions of differenced data should include a constant (Y intercept model) or not (regression through the origin or no-intercept model). Wilkinson et al. (1996) prefer regression with a constant (intercept model) unless prior knowledge requires a zero intercept while Neter et al. (1996, p. 516) indicate that differenced time series data should be analyzed with a no-intercept regression model. Although parsimonious models eliminate non-significant variables and elimination of a non-significant constant produces a no-intercept model, use of an intercept model where the intercept is non-significant and differs from zero by only a small sampling error will have minor consequences (Neter et al. 1996, p. 163). In all cases of the intercept regression model examined, the constant was non-significant and the pattern of variable significance was usually similar to that produced by the no-intercept model (a few cases occurred of significance in the no-intercept model when the intercept model was marginally non-significant). Thus, I have chosen to present results from the intercept model. Output from temperature models 1 and 2, with all variables included and with non-significant variables deleted (the "best" model), has been presented for completeness.

Residual plots of various types, e.g., residual on predicted value, autocorrelation and cross-correlation function plots of residuals 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 $\alpha \leq 0.05$.

The weight-length regression, with data logarithmically (base 10) transformed, was based (Ricker 1975) on subsamples of up to 60 elvers randomly chosen from each 5 mm length interval over the observed 50-75 mm length range, with a minimum subsample of 7 elvers in the length interval exceeding 70 mm. A sample of 248 elvers was selected from a total of 1,181 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 1997 elver dipnet fishery was conducted on 30 nights between April 26 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 on May 11 then none were caught until May 22. Catches peaked in late May (May 23 with about 69,000 elvers (18.18 kg)), then declined through two successively lower peaks until mid-June with cessation of fishing after June 20 (Table 1; Figure 4). The fishery catch totaled 123.03 kg wet weight (92.27 kg adjusted for 25% water retention) for an estimated 463,290 (95% CI ± 14,690) elvers. The mean catch per unit fishing effort (CPUE) was 0.57 $kg{\cdot}hr^{-1}$ ($N = 30$, SD = 0.716, range 0.0-2.29 $kg{\cdot}hr^{-1}$).

The elver traps became operational on May 3 but heavy rains on May 4 flooded the traps and continuing high, but declining, water levels kept the traps out of operation until May 14. Heavy rains on May 17 again flooded the traps, which returned to operation on May 21. Elvers were first observed beneath the bridge on May 20 and the first catch was recorded on the morning of May 22. The peak of the first wave of elvers occurred on May 25, followed by a larger wave peak on May 31 and a decline to two minor wave peaks on June 9 and 12 (Figures 4 and 5). The mean time between peaks was 6 d (range 3-9 d). Peaks in the trap catches were preceded 0-2 days by peaks in the commercial fishery catch. Over 100,000 elvers were caught during each of the two days of peak run in late May. Small catches (less than 500 elvers) continued after the first week of July until project termination on July 15. The total catch by elver trap was estimated as 1,018,620 (95% CI ± 60,920) elvers. Juvenile eels were first caught on May 22 and, although much less abundant (catch = 719 eels) than elvers, displayed run peaks similar to those of elvers until mid-June after which they also declined in abundance (Figure 5). 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 lower and upper left bank and lower right bank traps (looking upstream) catching similar total numbers (295,300 to 319,930) while the upriver right bank trap caught about one third as many (99,670) (Table 1; Figure 6). After about mid-June, the upriver trap on the left bank fished slightly more effectively than did the other traps. Peak catches also varied in magnitude among traps with peaks in downriver traps occurring 1-3 days before peaks in the upriver traps. During the May 31 run peak, the entrance of about 97,000 elvers into one trap severely tested its holding capacity at existing water flows and resulted in about a 40% mortality. Traps were subsequently emptied near midnight as well as in the morning during run peaks and no further mortalities occurred.

The elver run to the East River, Chester was estimated at 1,481,910 (95% CI ± 91,760) elvers. Fishing efficiency, or exploitation rate, by dipnetting was estimated at 31.3% (95% CI 27.5% - 35.5%). The estimates of run size and fishing efficiency have high precision (< ± 6.2%) but unaccounted for elver escapement, which is believed to have been low, would inflate the estimate of both run size and dipnet fishing efficiency.

Elver Instream Movements

Shoreline physical conditions changed with fluctuating water levels and velocities. Water velocity, as expected, was highly correlated ($r = 0.65$, $P < 0.0001$, $N = 32$) 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 May 17 until June 16 when another heavy rainfall temporarily increased the water level (Figures 4 and 7). Water velocities varied among sites depending upon their physical characteristics, averaging (all sites) 144 $cm{\cdot}s^{-1}$ until May 14 after which they declined to 41 $cm{\cdot}s^{-1}$ by mid-July (July 9-15).

No signs were observed of elver movement upstream beyond the waterfall or bypassing the traps before early June. During the second week of June, a few to several hundred elvers were observed clustered at bottlenecks in stream channel morphology, 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 waterfall. Some elvers may have progressed into the pond upriver of the waterfall prior to first detection but it is believed that few did so because, despite much activity, particularly at night, few were observed to actually pass the more significant obstacles. By June 10, 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 temporarily halted. However, continued decreases in water level and velocity required continued vigilance and maintenance, both night and day, and some elvers (perhaps a few thousand) undoubtedly made it to the headpond.

Environmental Effects on Run Timing

The 1997 elver run to the East River, Chester was delayed by a cold, wet spring with high stream discharge. The first commercial catch occurred on May 11, when the water temperature in the bay was about 6 °C (Figures 4 and 8). Elvers first entered the traps when mean daily water temperatures were about 8 °C in the estuary and 10.0 °C in the river. Daily water temperatures in bay and river increased gradually throughout the elver run, with moderate variability in temperatures until late May when variability, particularly in the bay, increased. The difference in water temperature between river and bay varied between 0.4 and 2.5 °C until May 22 after which the difference ranged between 1.0 and 8.4 °C (Figure 9). River water levels periodically fluctuated 10-20 cm in response to rainfall during May, then declined steadily until mid-June when rainfall briefly increased the water level before the decline continued through mid-July.

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 June 11, which followed by 11 d the second wave of elvers entering the river (Tables 3 and 5; Figure 4). As the third and fourth (and much smaller) pulses of elvers peaked on June 12 and June 24, river height began to show, after June 18, a negative effect on daily elver count in both the river temperature ($P < 0.02$) and temperature difference ($P < 0.04$) models.

Dropping the non-significant variables river temperature and tide height from the temperature model and temperature difference models, as required by standard statistical procedure, makes both models equivalent, with only river height remaining in each. The reduced model, containing only river height, produced results similar to those from the full models (Table 4). Two of the four major elver run peaks occurred when tides were rising between 2100-0300 h and falling after 0300 h while the remaining peaks occurred when the tides were rising between 1800-2100 h or between 1800-2400 h.

The t-values of Tables 3, 4 and 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 in this type of biological data. The final P-value indicates the significance of the linear relations between the daily elver count and the various environmental variables.

Elver Biological Characteristics

Total Length and Weight

The total sample ($N = 1{,}181$, including 22 reclassifications) of elver lengths was roughly normally distributed, with a mean of 60.34 ± 0.20 mm (95% CI), median of 60.24 mm, and range from 50.1 to 73.0 mm (Figure 10). Elver weights were right skewed, with a mean of 0.170 ± 0.002 g (95% CI), median of 0.170 g, and range from 0.07 to 0.37 g. Elver mean (median) length decreased for the first four weeks of the run from 64.18 (64.04) mm to 59.40 (59.13) mm then increased to 60.78 (60.89) mm in week six before declining to 58.88 (58.30) mm at the end of the run while elver mean (median) weight decreased steadily throughout the run from 0.218 (0.215) g to 0.129 (0.130) g (Figure 11). Elvers declined about 5.3 mm (8%) in length and 0.09 g (41%) in weight between mid May and mid July. Both unusually long elvers and unusually heavy elvers appeared throughout the run. High length was not necessarily coupled with high weight. Weekly means varied significantly for elver length ($F = 32.1$, df = 8, 1,172, $P < 0.0001$) and weight ($F = 68.1$, df = 8, 1,172, $P < 0.0001$). Means that do not have a letter in common are significantly different from each other:

Week	1	2	3	6	5	4	8	9	7
Length (mm)	64.18 x	62.66 x	60.99 y	60.78 y	59.46 z	59.40 z	59.28 z	58.88 z	58.79 z
Week	1	2	3	5	4	6	7	8	9
Weight (g)	0.218 v	0.208 v	0.194 w	0.169 x	0.166 x	0.156 xy	0.155 y	0.139 z	0.129 z

Juvenile lengths and weights were right skewed; few individuals exceeded 100 mm in length and 1.5 g in weight (Figures 10 and 11). A few larger juvenile eels entered the traps between mid May and early July (weeks 1 to 7).

Elver weight increased with increasing length in a slightly curvilinear manner over the length range 50-73 mm (Figure 12A). The predictive linear equation describing the relation is:

$$\text{Log}_{10} W = -6.1752 + 3.0296 \text{ Log}_{10} L \qquad N = 248,\ R^2_{adj} = 0.66,\ P < 0.0001$$

where W = weight (g) and L = length (mm) (Figure 12B). The standard errors and 95% confidence limits (in parentheses) for the regression coefficients are: constant = 0.2457, (-6.6592 to -5.6912); Log_{10} L = 0.1381, (2.7576 to 3.3016).

Pigmentation

The degree of elver pigmentation increased progressively over the run, with most elvers in pigmentation stage 3 during May 18-24, stage 4 by May 25-31, and stages 6 and 7 after June 8-14 (Figure 13). Pigment stage 1 (glass) elvers were not found after May 28 and were infrequent (1.8%) even during the first week of the run while a few stage 7 elvers also appeared during the first week. Glass eels composed less than 0.4% of the total trap catch but were likely more abundant in the early (late April) fishery catch. Six elvers of pigment stage 7 and lengths of 62-68 mm and weights of 0.20-0.28 g were observed during the first week of the run when most elvers were of pigment stage 4 or less and comparable lengths and weights. On May 23, one elver of pigment stage 3 had a length of 73 mm and weight of 0.30 g.

Elvers first appeared at Site A (Figure 3) on May 27, followed by peaks in abundance on May 29, June 4, and June 11, with the last capture on June 26 (Table 2). At Site B, elvers first appeared on June 2 with peaks in abundance on June 5, June 9, and June 13. Small numbers of elvers continued to be caught into mid-July. Elvers first appeared at Site C on July 4 and at Site D on July 5. At Site A, elver mean lengths (N = 30) declined as the run progressed (lengths without a letter in common are significantly different):

Date	May 28	June 2	June 4	June 6	June 11
Length (mm)	63.69 z	62.38 zy	61.46 yx	60.87 yx	60.45 x

At Site B, the mean length of elvers on June 13 was 61.55 mm (N = 30, SD = 2.19).

Four days passed between the first occurrence of elvers at the traps and at Site A. The first and second peaks in abundance at the traps (May 25 and May 31) were also evident at Site A four days later (May 29 and June 4). A smaller, third peak (June 9) at the traps showed at Site A two days later (June 11) but a fourth peak (June 12) did not appear in the tube trap catch. The first peak in elver abundance at Site A appeared at Site B seven days later (May 29-June 5) while the second and largest wave of elvers to Site A took 9 days (June 4-13). Based on the distances and time of travel between sites, the rate of travel averaged 125 $m \cdot d^{-1}$ between the release site in the lower headpond and Site A, 30-40 $m \cdot d^{-1}$ between Site A and Site B, and 18 $m \cdot d^{-1}$ between Sites B and D and between Sites A and C. Overall, elvers traveled the 1.37 km between the river mouth and Site D at 32 $m \cdot d^{-1}$ and the 1.08 km to Site C at 26 $m \cdot d^{-1}$. The four day difference between run peaks at the river mouth and at Site A was reflected in the mean lengths at each site (63.9-63.2 mm on May 23-26 at the river mouth and 63.7 mm at Site A on May 28) as was the 7-9 d difference between peak abundance at Sites A and B (mean length of 61.5 mm on June 4 at Site A and 61.6 mm on June 13 at Site B).

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 press). Elver migration occurs in three phases: coastal approach, estuarine phase with transition from sea to freshwater, and upstream migration and distribution within the river (Cantrelle 1981). In 1997, elvers were first caught by the commercial fishery in the upper estuary on May 11 although fishing activity began on May 1 and the first wave of elvers did not enter freshwater before May 22. 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 1981; Élie and Rochard 1994). In 1996 (Jessop 1997), the first catch of elvers by the commercial fishery and the first entrance of elvers into freshwater occurred about two weeks earlier than in 1997. At the time elvers entered freshwater, river water temperatures were 10.9 °C in 1997 and 9.7 °C in 1996 (Jessop 1997) while river water levels were 1.4 m in both years.

Once migration had begun, the delay of 1-2 d (1-3 d in 1996; Jessop 1997) 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 1981; Gandolfi et al 1984; Dutil et al. 1987). 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 1981). 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 1997 estimated run of 1.48 million elvers to the East River, Chester (drainage area = 134 km^2) and run density of 11,000 elvers·km^{-2} of river drainage area exceeded that in 1996 (Jessop 1997) by 32% (1.12 million elvers, 8,400 elvers·km^{-2}). The elver run to the East River, Sheet Harbour (drainage area = 526 km^2) was estimated in 1997 as 0.73 million elvers (1,380 elvers·km^{-2}) and in 1996 as 0.34 million elvers (640 elvers·km^{-2}) (Jessop, unpublished data). Run densities of the larger European elver (about 70 mm in the northern part of their range) averaged 159 elvers·km^{-2} (range 20-380 elvers·km^{-2}) over nine years in the Imsa River, Norway (drainage area = 128 km^2) (Vøllestad and Jonsson 1988), and 561 elvers·km^{-2} in the River Arguenon, France (drainage area = 383 km^2 (Legault 1994). The hypothesis that elver runs are proportional to annual river discharge (drainage area) may apply only within geographic areas of similar elver abundance in coastal waters since elver catch varies over wide geographic areas in North America (Jessop, in press) 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·sec^{-1} at the lip of the falls early in the run and about 50 cm·sec^{-1} later in the run, a drop of about 0.6 m at the fall line, and active measures to prevent elvers from moving upstream are believed to have basically eliminated any such movement in 1996 (Jessop 1997) and 1997. American elvers have difficulty swimming short distances or cannot maintain position at water velocities greater than 35 cm·sec^{-1} and most will not swim at water velocities exceeding 25 cm·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·sec^{-1} and by the larger European elver at water velocities exceeding 50 m·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 to the stream are high, 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 1981). A dipnet fishery exploitation rate of 29.5% in 1996 (Jessop 1997) and 31.3% in 1997 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.

The rate of elver migration upstream in the East River, Chester, during their first summer decreased with increasing gradient (and stream velocity) from 125 m·d^{-1} through a flatwater zone to

18 m·d^{-1} through a zone with gradients up to 4-8%. Elvers took about six weeks (from May 22) to migrate the first 1.4 km upstream due to the gradients encountered and higher water velocities during the early part of the run. Decreasing seasonal water levels and velocities, increasing elver size due to summer growth, and low gradients (≤ 0.9%) to the first major lakes should permit a migration rate of perhaps 125 m·d^{-1} and enable elvers to reach Big Whitford Lake on the main stem (6.6 km from the mouth) by mid-August, Little Whitford Lake on a tributary to the main stem (4.2 km from the mouth) by late July and Connaught Lake on the Canaan River (9.1 km from the mouth) by early September.

In streams with moderate-to-high flows and gradients, elvers evidently migrate only a short distance, perhaps a few kilometers, upstream during their first year (Haro and Krueger 1988; Dutil et al. 1989). American elvers migrated upstream at about 6 m·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). However, in the Saint John River, New Brunswick, elvers once reached the Mactaquac Dam 148 km upstream of the river mouth (gradient of 0.003%) by late June or early July (LeBlanc 1973; Jessop, personal observation), for a migration rate of about 2.4 km·d^{-1} between April 1 and July 1.

If elvers reach and enter the first lakes on the main stem of the East River, Chester, and the Barry's Brook, Canaan River, and unnamed (to Little Whitford Lake) tributaries, and uniformly distribute themselves along the way, the resultant density would approximate 2,800 elvers·ha^{-1} (1996) to 3,700 elvers·ha^{-1} (1997). These densities exceed the maximum stocking rates (1,600 elvers·ha^{-1}) utilized or recommended (100-500 elvers·ha^{-1}) in Europe (Moriarty 1990b; Moriarty et al. 1990; Klein Breteler 1992), although densities as high as 10,000-15,000 elvers·ha^{-1} have been used in some highly productive Danish streams (Berg and Jørgensen 1994). In low pH, low biological production streams such as the East River, elvers could experience higher first year mortality rates at the elver densities observed than at lower densities.

Elvers entered the river in large numbers only after river temperatures reached 10 °C in both 1996 and 1997, a value similar to the 11 °C threshold suggested by Helfman et al. (1984) for Georgia, 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 not significantly influenced by river temperature, river level, or nighttime tide height until June 18, after which river level became a significant factor. Over 95% of the run had entered the river by June 18. However, tidal conditions must have played some role because of the observation that elver run peaks occurred during rising or peaking nighttime tide heights. During 1996, river temperature, river level, and nighttime tide height significantly influenced the run during the period in which 93% of the elver run had entered the river (Jessop 1997).

The increase in American elver migration with increasing river temperatures through most of the 1996 run (Jessop 1997) and absence of a temperature effect in 1997 differs from observations by Martin (1995), who noted a temperature effect only during the start of the run and near the end while 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 1981) probably applies to American elvers and would be consistent with the observed temperature effect in 1996 but does not account for the absence of a temperature effect in 1997.

No significant effect on the elver run was found for the difference between river and bay water temperature in either 1996 (Jessop 1997) or 1997. The hypothesis that elver migration peaks when sea and freshwater temperatures become nearly equal (Gandolfi et al. 1984) could not be supported nor could the conclusion by Martin (1995) that a high temperature difference between river and bay was preferred by elvers.

The collinearity of water temperature and level confounds interpretation of the specific effects of each variable. Water temperatures decreased with increasing water level in both 1996 (Jessop 1997) and 1997 even after detrending by differencing. In 1997, neither high water discharge nor decreasing water temperatures affected trap catches, unlike in 1996 when both variables decreased trap catch. The difference between years is largely accounted for by the differences in seasonal water level patterns, with 1996 water levels fluctuating several times during the run, with differences of 0.13-0.22 m, while 1997 water levels steadily declined (maximum rise of 0.03 m) during the run.

The statement by Sorensen and Bianchini (1986) that "no study of a location with a well defined interface (between estuary and stream) has shown a correlation between migration and rainfall" appears outdated in light of recent results. Martin (1995) reported a negative effect on elver upstream migration by a high water level at the start of the elver run and a positive effect near the end of the run. Jessop (1997) found no effect on the elver run by water level when water temperature was included in the model but found a significant positive effect on elver daily abundance by water level during the main part of the run when water temperature was not included. In this study, the seasonal pattern of river temperature and water level was such that river level had a significant negative effect (increased river level decreased the elver catch) and river temperature had no significant effect. 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 may be typical (Jellyman 1977, 1979; Sorensen and Bianchini 1986) although a relation is sometimes found (Jellyman and Ryan 1983).

In 1997, no difference occurred between regression models in the dates at which environmental effects became significant. In 1996, the difference (Jessop 1997) in the dates at which environmental effects became significant in the reduced temperature and temperature difference models 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 (number of days in the time series, which are small for the first two analysis dates in 1996 and 1997), 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) at moderate-to-higher tide ranges (1.5-3.8 m) but its importance may be influenced by local hydrographic conditions or be reduced by limited (1-1.5 m) tidal range (Jellyman 1977; Sorensen and Bianchini 1986). In 1997, nighttime tidal height had no significant effect on the elver migration to the East River, Chester, but the strong negative effect of nighttime tidal stage on daily elver count during 1996 (Jessop 1997) contrasts with other North American studies. The mean tide range in the estuary of the East River, Chester, is 1.6 m (Anon. 1997). 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 in 1996 results from the lagged effect of tide at the trap sites; tides 3 d earlier than the count day were declining from a peak 4-5 d earlier. 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 (about 50 m) between the fishery site and upstream trap sites. Jellyman (1979) reported 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 in 1996 (Jessop 1997), 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. In 1997, all four elver run peaks occurred with tides rising at some time between 1800 and 2400 h. Ideally, any measure of tidal effect on the elver run should consider both tidal stage (rise, fall) as well as height. Evidently, the seasonal pattern of environmental conditions varies sufficiently within and between years that different conditions may influence the elver run in any given year. This may account for the some of the wide variability noted by Martin (1995) in the results of other studies on the effects of environmental factors on elver runs.

Both length and weight of American elvers from the East River, Chester, declined slowly throughout the run in 1996 (Jessop 1997) and 1997. The declining trend in length may not be so evident in some years, particularly when mean length increases during the start of the run as in 1996 and growth occurs near the end of the run if elvers have begun feeding, e.g., East River, Sheet Harbour (Jessop, unpublished data). Length declines during the migratory period 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 1981). 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 biological implications of seasonally decreasing elver length and weight are uncertain. Mortality rates of larval and juvenile marine fishes have often been hypothesized to decrease with increasing fish size but mortality rates may, in fact, be constant during these life stages (Pepin 1993). At older ages, the annual mortality rate of eels does decline with increasing age (De Leo and Gatto 1995).

Elver weight increased curvilinearly with length between 50 and 76 mm, becoming markedly curvilinear during the first year of growth (Peterson and Martin-Robichaud 1994) and with very evident curvilinearity for larger eels (Tesch 1977).

The increase in elver pigmentation over the run was more abrupt in 1997 than in 1996 (Jessop 1997), perhaps due to the delayed entry of elvers in 1997 since pigmentation 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 1981). 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. The few elvers of high length and weight and low pigmentation at the start of the elver run may derive from unusually large leptocephali. The few elvers with high pigmentation stage and average length and weight found early in the run may be, and most likely are, small juveniles from late in the previous years run or they may be elvers with very rapid development of pigmentation. Only ageing by otolith analysis will enable a correct determination.

Acknowledgements

This study was enabled by the Joint Project Agreement between the Department of Fisheries and Oceans and the elver fisher group consisting of W. Carey, R. Hamilton, and P. Holland. The elver fishery on the East River, Chester was conducted by fishers under the supervision of W. Carey. The Nova Scotia Department of the Environment graciously loaned a trailer for use on site and provided electrical power courtesy of G. Searle and H. Meisner. Term fishery technicians N. Caron and B. Zisserson contributed much to the success of the project. Thanks are also due to J. Hackett and H. Carachristi for assistance in obtaining and editing digital versions of the topographic maps used.

References

Anon. 1997. 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.

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

Cantrelle, I. 1981. Etude de la migration et de la pêche de civelles (*Anguilla anguilla* L. 1758) dans l'estuaire de la Gironde. Thèse Doct. 3e 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.

De Leo, G. A., and M. Gatto. 1995. A size and age-structured model of the European eel (*Anguilla anguilla* L.). Can. J. Fish. Aquat. Sci. 52: 1351-1367.

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.

Elie, P., R. Lecomte-Finiger, I. Cantrelle, and N. Charlon. 1982. Définition des limites des différents stades pigmentaires durant la phase civelle d'*Anguilla anguilla* L. (Poisson téléostéen anguilliforme). Vie Milieu 32: 149-157.

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.

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. 96/118. 15 p.

Jessop, B. M. 1997. The biological characteristics of, and efficiency of dip-net fishing for, American eel elvers in the East River, Chester, Nova Scotia. Diadr. Fish. Div. Doc. No. 97-01. 29 p.

Jessop, B. M. in press. 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.

LeBlanc, R. 1973. Elver survey in New Brunswick waters. Final Report, New Brunswick Dept. of Fisheries and Envir., Fredericton. 92 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.

Pepin, P. 1993. An appraisal of the size-dependent mortality hypothesis for larval fish: comparison of a multispecies study with an empirical review. Can. J. Fish. Aquat. Sci. 50: 2166-2174.

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.

Table 1. Estimated[a] trap and commercial fishery dipnet catches of American eel elvers, by date, from the East River, Chester, 1997.

	Trap Number						
Date	1	2	3	4	Total	Juvenile	Fishery
April 26	-	-	-	-	-	-	0
April 27	-	-	-	-	-	-	-
April 28	-	-	-	-	-	-	-
April 29	-	-	-	-	-	-	-
April 30	-	-	-	-	-		-
May 1	-	-	-	-	-	-	0
May 2	-	-	-	-	-	-	-
May 3	-	-	-	-	-	-	0
May 4	-	-	-	-	-	-	-
May 5	-	-	-	-	-	-	-
May 6	-	-	-	-	-	-	-
May 7	-	-	-	-	-	-	-
May 8	-	-	-	-	-	-	0
May 9	-	-	-	-	-	-	-
May 10	-	-	-	-	-	-	-
May 11	-	-	-	-	-	-	3410
May 12	-	-	-	-	-	-	-
May 13	-	-	-	-	-	-	-
May 14	-	-	-	-	-	-	-
May 15	-	-	-	-	-	-	-
May 16	-	-	-	-	-	-	-
May 17	-	-	-	-	-		0
May 18	-	-	-	-	-	-	-
May 19	-	-	-	-	-	-	-
May 20	-	-	-	-	-	-	0
May 21	-	-	-	-	-	-	0
May 22	0	51	0	4	55	4	45450
May 23	0	16.340	190	480	17,010	29	68860
May 24	0	18,790	6,380	6,650	31,820	68	35420
May 25	0	66,230	36,860	8,950	112,040	44	16760
May 26	0	8,550	8,910	6,060	23,520	11	28300
May 27	0	14,990	11,360	6,900	33,250	32	-
May 28	0	10,130	1,560	650	12,330	5	-
May 29	0	27,970	1,730	870	30,570	25	62140
May 30	150	3,550	3,500	1,520	8,720	70	52090
May 31	20,730	0	0	117,210	137,940	53	31220
June 1	3,330	52,180	10,580	30,640	96,730	59	25450
June 2	1,770	25,160	26,330	30,840	84,100	37	3730
June 3	16,070	22,670	25,250	460	64,450	10	0
June 4	19,190	-	14,540	9,560	43,290	15	0
June 5	15,520	7,850	5,280	2,890	31,540	20	7120
June 6	5,760	3,550	7,960	550	17,820	18	0
June 7	2,050	3,130	11,120	4,430	20,730	13	-
June 8	1,570	1,590	10,960	6,940	21,060	11	0
June 9	114	170	15,690	17,120	33,090	14	11160
June 10	76	290	13,880	3,520	17,770	9	-
June 11	-	170	970	13,820	14,960	12	57670
June 12	3,860	-	25,790	20,410	50,060	10	14510
June 13	620	1,190	11,230	8,180	21,220	16	-
June 14	2,130	1,270	8,100	3,730	15,230	8	-
June 15	1,810	1,320	8,610	2,030	13,770	13	-
June 16	1,860	2,730	7,480	1,130	13,200	5	0
June 17	220	2,320	540	510	3,590	7	0
June 18	300	135	540	160	1,130	2	-
June 19	-	300	510	220	1,030	1	0
June 20	5	33	41	42	121	0	0
June 21	40	300	510	135	990	4	-
June 22	-	270	780	1,190	2,240	5	-
June 23	460	76	2,350	190	3,080	1	-
June 24	380	1,670	4,130	2,270	8,450	0	-
June 25	108	1,620	1,590	1,270	4,590	3	-
June 26	56	27	1,730	1,810	3,620	0	-
June 27	12	700	135	700	1,550	2	-
June 28	23	510	220	570	1,320	1	-
June 29	17	1,130	220	840	2,200	2	-
June 30	77	1,510	56	1,510	3,160	2	-
July 1	160	1,590	1,620	380	3,750	5	-
July 2	730	590	1,970	1,130	4,420	16	-
July 3	160	890	1,190	300	2,540	8	-
July 4	59	60	270	190	580	1	-
July 5	76	14	620	190	900	5	-
July 6	18	21	380	320	740	4	-
July 7	-	13	17	135	165	2	-
July 8	26	56	108	160	350	4	-
July 9	25	-	270	11	310	9	-
July 10	12	-	270	108	390	0	-
July 11	15	-	270	36	320	5	-
July 12	16	-	83	14	113	5	-
July 13	11	-	.71	4	86	5	-
July 14	7	-	135	2	144	5	-
July 15	48	-	410	15	470	6	-
Total	99,670	303,710	295,300	319,940	1,018,620	705	463,290

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

Table 2. Tube-trap catch of American eel elvers, by date and site, in the East River, Chester, 1997.

	Site			
Date	A	B	D	C
May 24	0	0	-	0
May 25	0	0	-	0
May 26	0	0	-	0
May 27	167	0	-	0
May 28	228	0	-	0
May 29	722	0	-	0
May 30	570	0	0	0
May 31	167	0	0	0
June 1	323	0	-	-
June 2	399	1	0	0
June 3	76	2	-	-
June 4	4,256	12	-	-
June 5	1[a]	37	-	-
June 6	133	5	0	0
June 7	171	24	-	-
June 8	4	2	-	-
June 9	11	50	0	0
June 10	14	0	-	-
June 11	133	16	0	0
June 12	32	76	-	-
June 13	1	342	0	0
June 14	0	6	0	0
June 15	1	4	0	0
June 16	0	15	0	-
June 17	1	5	-	0
June 18	0	0	0	0
June 19	0	0	0	0
June 20	0	0	0	0
June 21	0	0	-	0
June 22	0	0	-	-
June 23	10	4	0	0
June 24	35	3	0	0
June 25	5	0	0	0
June 26	2	0	0	0
June 27	0	2	0	0
June 28	0	0	-	-
June 29	0	0	-	-
June 30	0	1	0	0
July 1	0	23	-	-
July 2	0	3	0	0
July 3	0	0	-	-
July 4	0	0	0[b]	1
July 5	0	0	2	0
July 6	0	2	4	0
July 7	0	0	4	3
July 8	0	0	3	0
July 9	0	6	7	0
July 10	0	0	0	0
July 11	0	4	0	1
July 12	0	2	4	1
July 13	0	0	2	0
July 14	0	0	0	0

[a]Trap improperly set.

[b]Elvers present near trap.

Table 3. *t*-Values and their significance, degrees of freedom (df), adjusted multiple R^2 values and regression significance (P) for parameters of the multiple regression model $E = B_0 + B_1 T + B_2 H + B_3 M$ 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.

	t-Values (Probability)					
Date	River temperature	River height	Tide height	df	R^2	*P*
May 30	-1.30 (0.26)	-0.79 (0.48)	0.05 (0.96)	3,4	0.25	0.29
June 6	-0.93 (0.37)	-1.87 (0.09)	-0.22 (0.83)	3,11	0.08	0.29
June 11	-0.84 (0.41)	-1.96 (0.07)	-0.13 (0.90)	3,16	0.10	0.21
June 18	-0.85 (0.41)	-2.42 (0.020)	0.42 (0.68)	3,23	0.14	0.089
June 27	-0.78 (0.44)	-2.79 (0.009)	0.65 (0.52)	3,32	0.14	0.051

Table 4. *t*-Values and their significance, adjusted multiple R^2 values, degrees of freedom (df), and regression significance (P) for parameters of the regression model $E = B_0 + B_1 H$ where E = daily elver trap total count; B_0 = intercept; B_i = coefficient for each parameter; H = daily river gauge height (level).

	t-Values			
Date	River height	df	R^2	*P*
May 30	-0.90	1,6	0.0	0.40
June 6	-1.87	1,13	0.15	0.085
June 11	-2.07	1,18	0.15	0.054
June 18	-2.46	1,25	0.16	0.021
June 27	-2.77	1,34	0.16	0.009

Table 5. *t*-Values and their significance, degrees of freedom (df), adjusted multiple R^2 values and regression significance (*P*) for parameters of the multiple regression model $E = B_0 + B_1 (\Delta T) + B_2 H + B_3 M$ where E = daily elver trap total count; B_0 = intercept; B_i = coefficient for each parameter; ΔT = difference between daily mean river and estuary water temperatures lagged two days; H = daily river gauge height (level); M = maximum tide height for the night preceding the elver count.

	t-Values (Probability)					
Date	Temperature difference	River height	Tide height	df	R^2	*P*
May 30	-2.10 (0.10)	1.86 (0.14)	2.85 (0.046)	3,4	0.49	0.14
June 6	0.003 (0.99)	-1.36 (0.20)	0.30 (0.77)	3,11	0.01	0.41
June 11	0.14 (0.89)	-1.76 (0.097)	0.44 (0.66)	3,16	0.06	0.28
June 18	-0.08 (0.94)	-2.23 (0.036)	0.82 (0.42)	3,23	0.12	0.12
June 27	0.11 (0.99)	-2.66 (0.012)	0.66 (0.52)	3,32	0.12	0.07

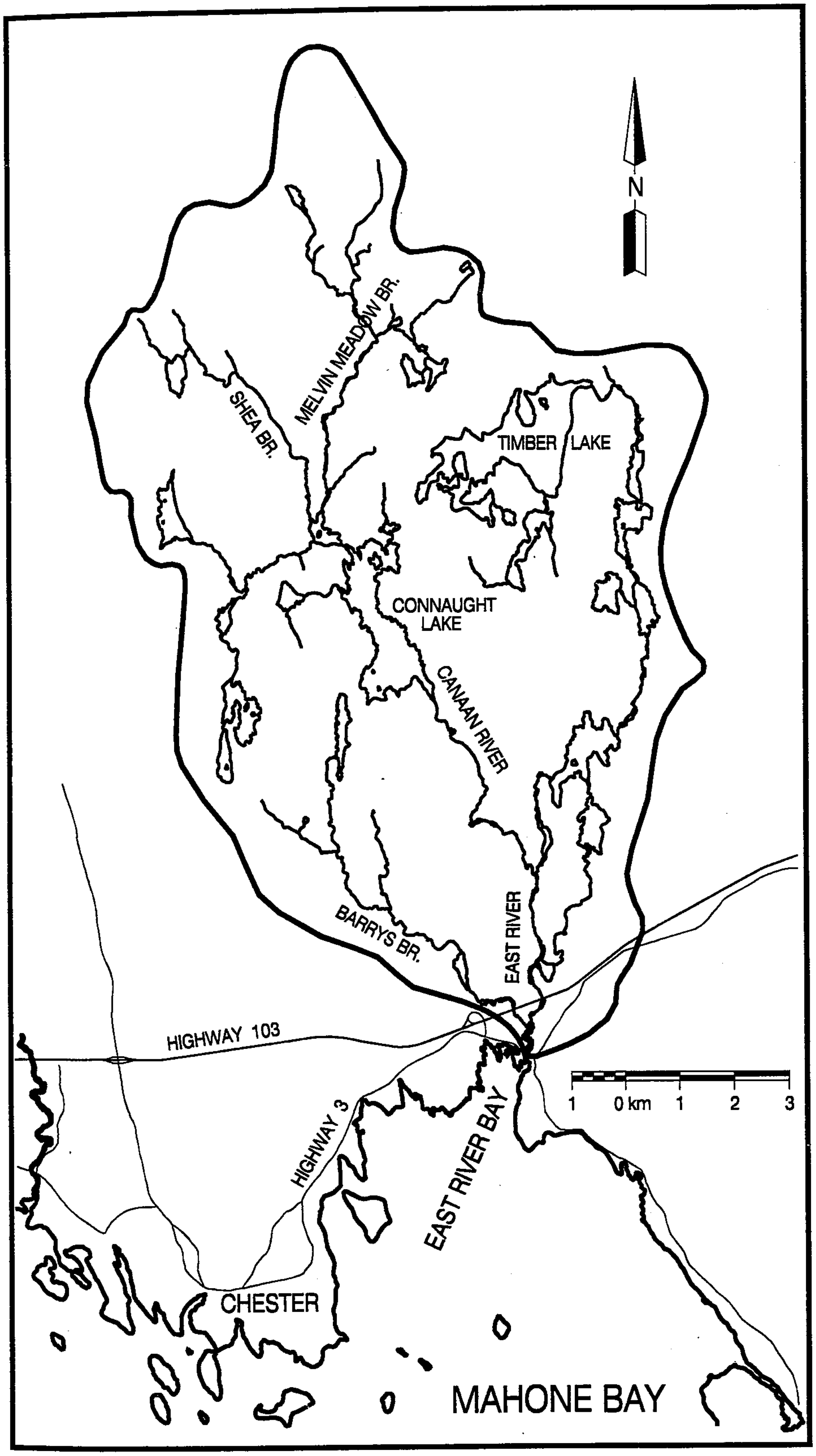

Figure 1. Drainage basin of the East River, Chester, Nova Scotia (area 134.0 km^2).

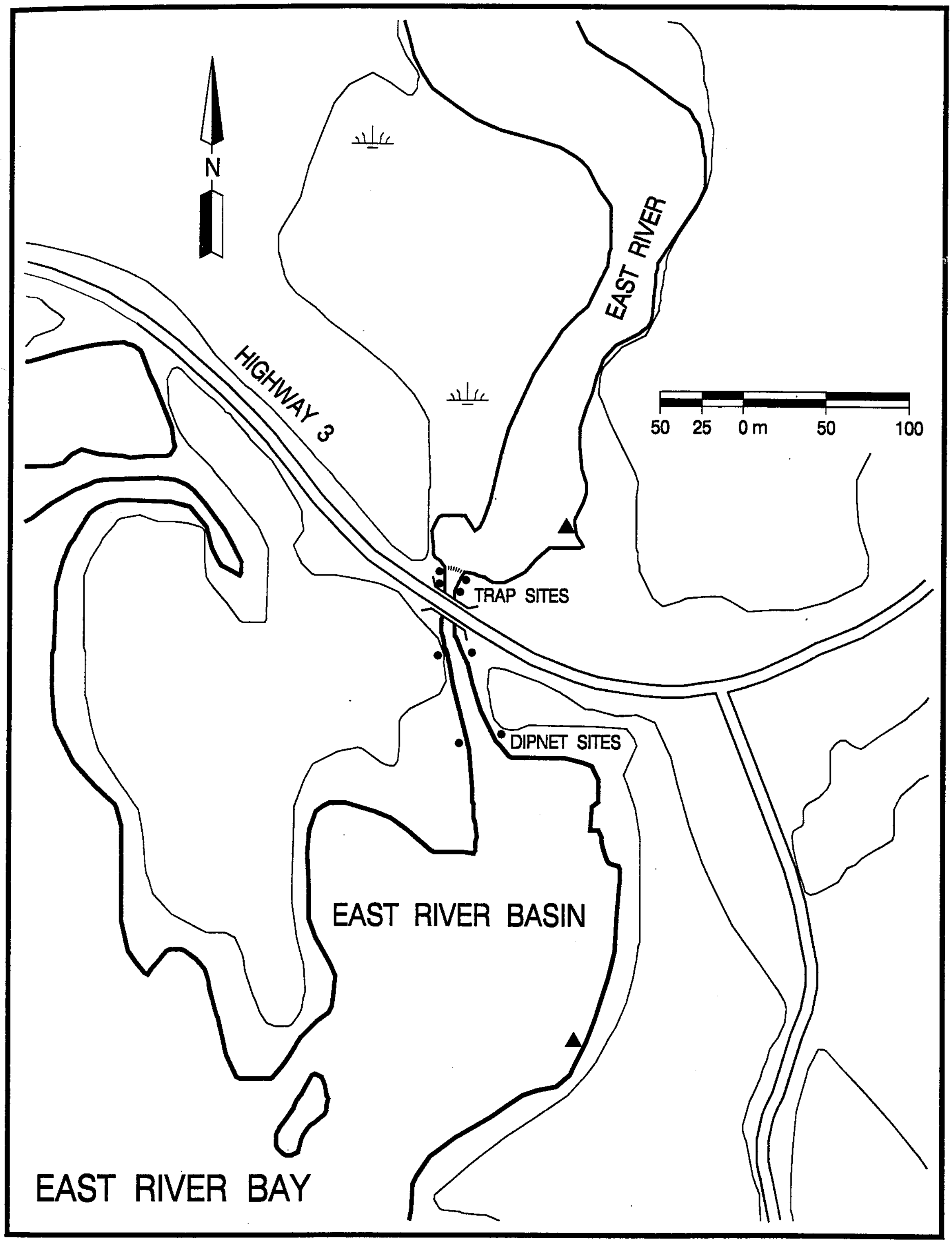

Figure 2. Elver trap and range of dip net fishing locations on the East River, Chester, Nova Scotia. Solid triangles indicate thermograph sites.

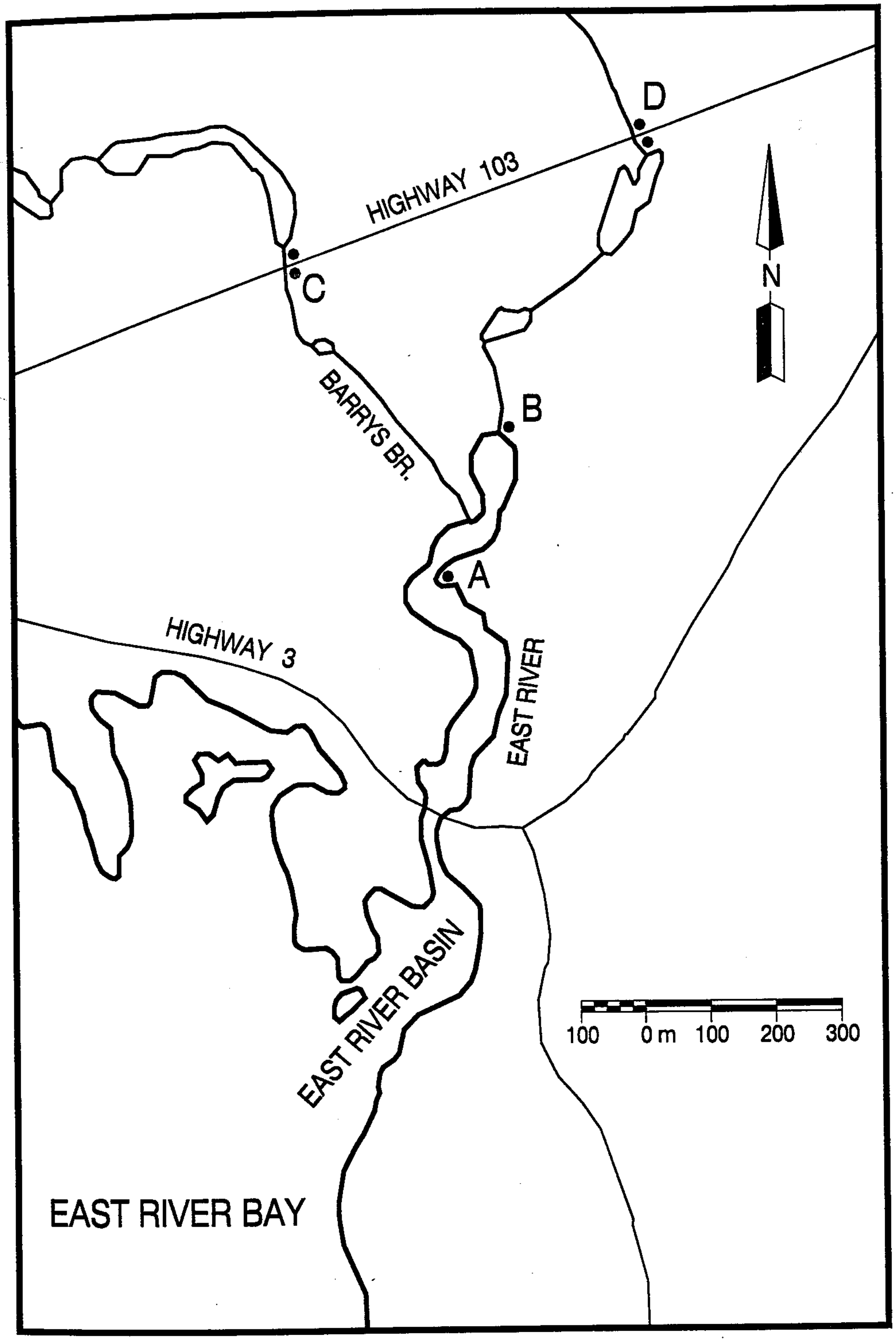

Figure 3. Tube-trap sites in the East River, Chester, Nova Scotia, 1997. At sites C and D, traps were relocated upstream of the highway after July 4.

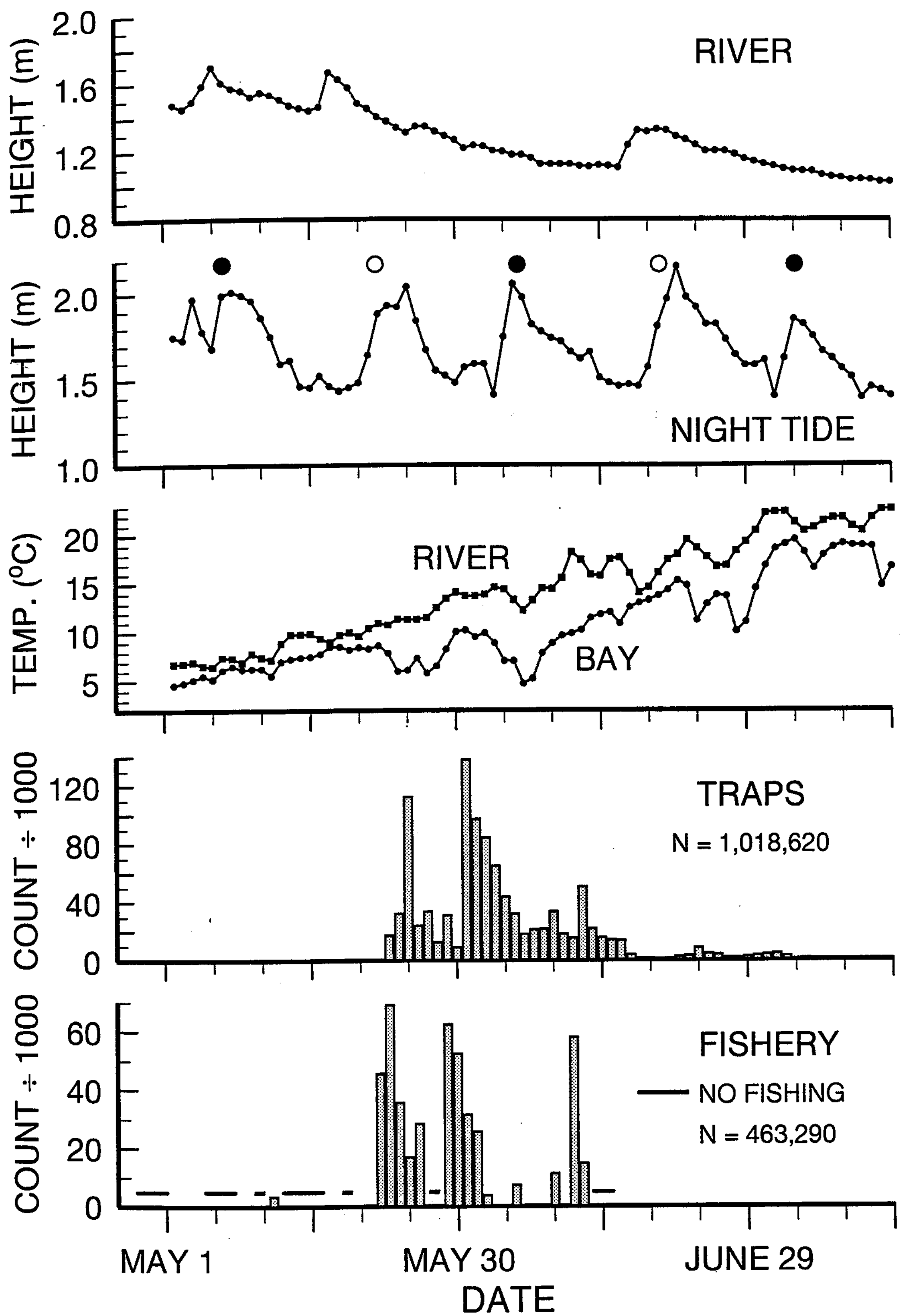

Figure 4. Daily river water levels, nighttime tide heights, river and bay water temperatures, elver trap counts, and dipnet fishery catches for the East River, Chester, Nova Scotia, 1997.

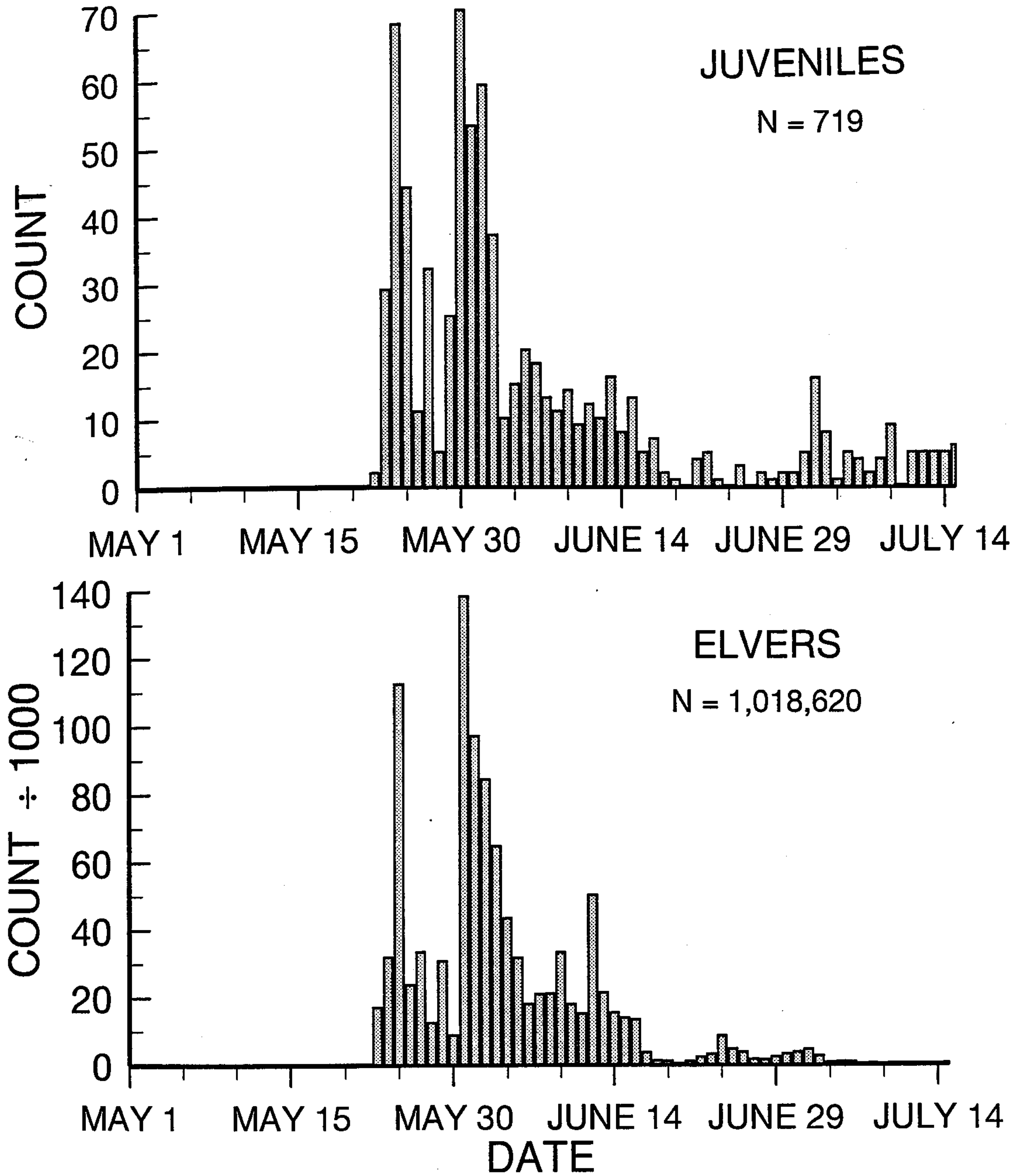

Figure 5. Daily counts of elver and juvenile American eels from the East River, Chester, Nova Scotia, 1997.

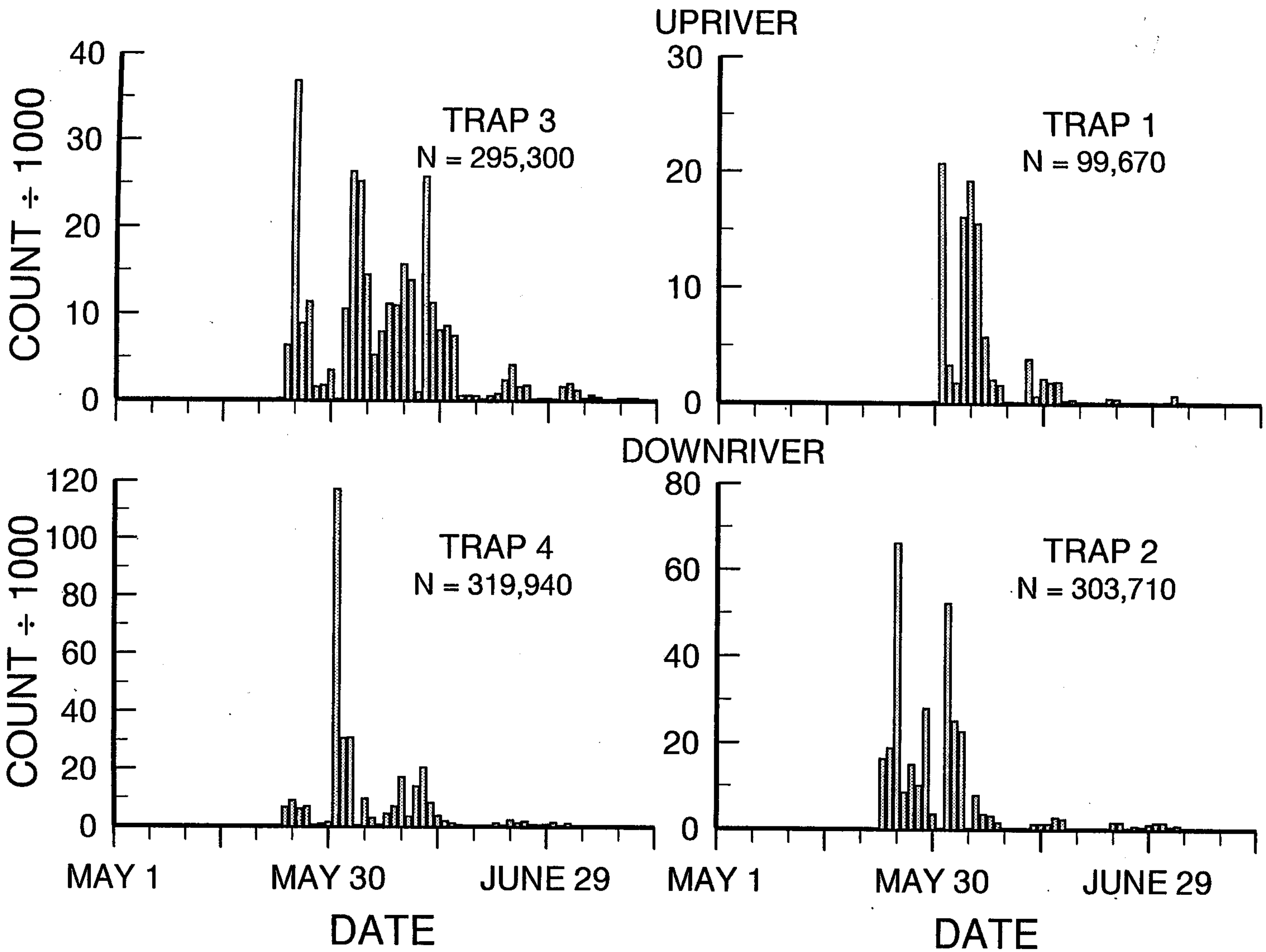

Figure 6. Daily counts of American eel elvers, by trap, from the East River, Chester, Nova Scotia, 1997. Traps 1 and 2 were sited on the true right bank, traps 3 and 4 on the left bank.

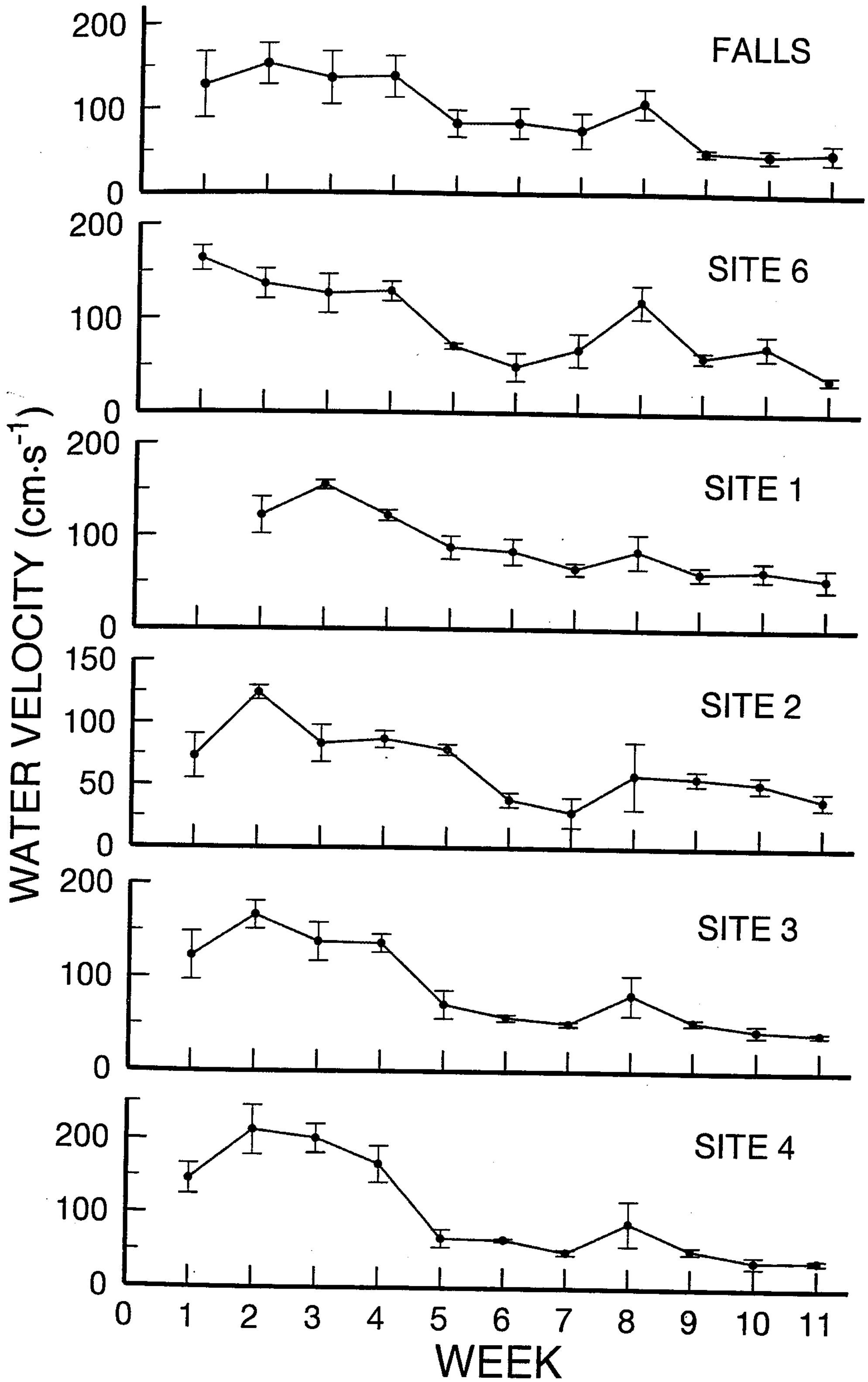

Figure 7. Mean (± 1 SE) water velocity, by site and week, for the East River, Chester, Nova Scotia, 1997. Weeks (in brackets): May 1-2 (1), May 4-10 (2), May 11-17 (3), May 18-24 (4), May 25-31 (5), June 1-7 (6), June 8-14 (7), June 15-21 (8), June 22-28 (9), June 29-July 5 (10), July 6-13 (11).

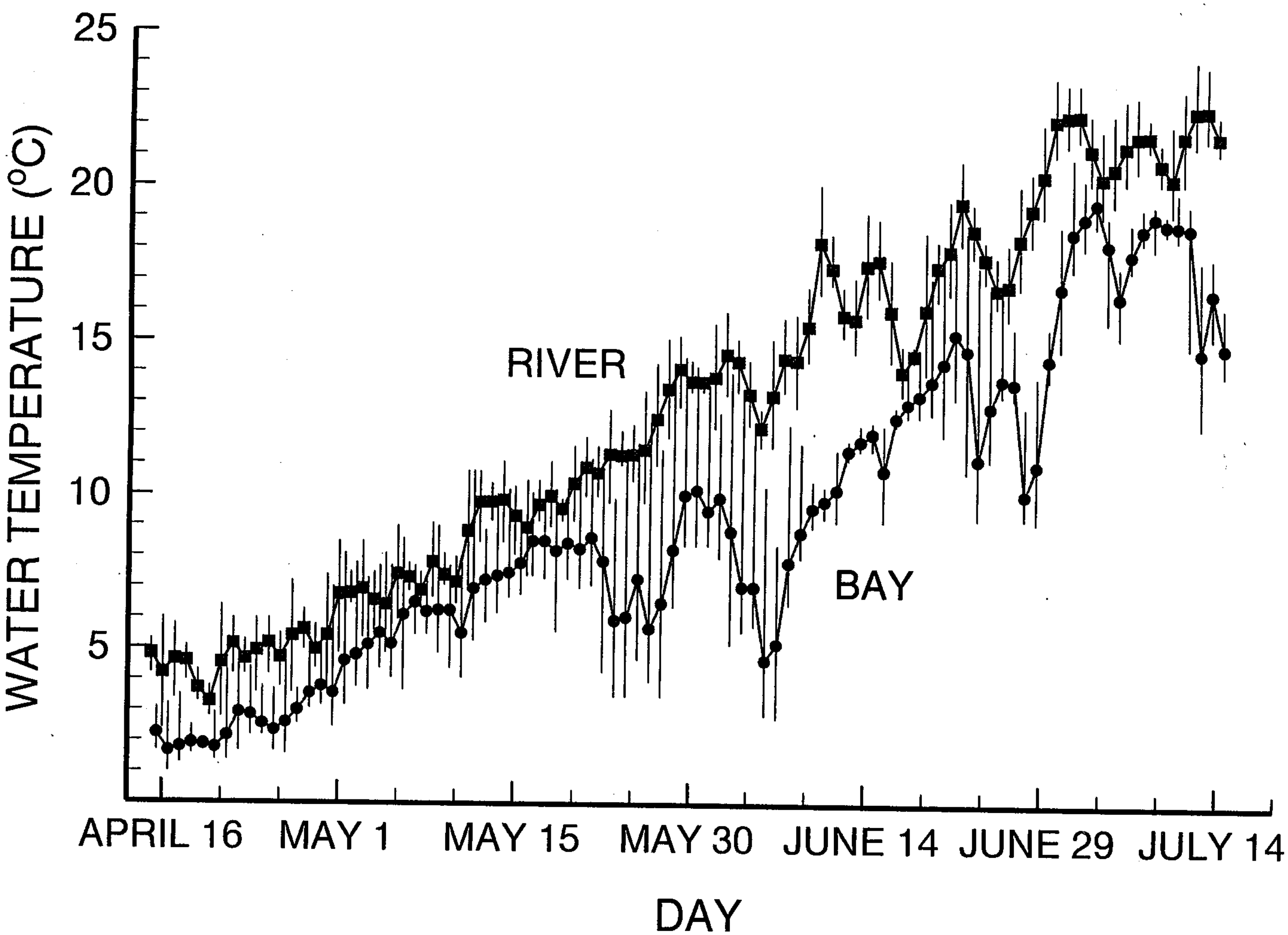

Figure 8. Daily mean and range of water temperatures from the East River, Chester and East River Basin, Nova Scotia, 1997.

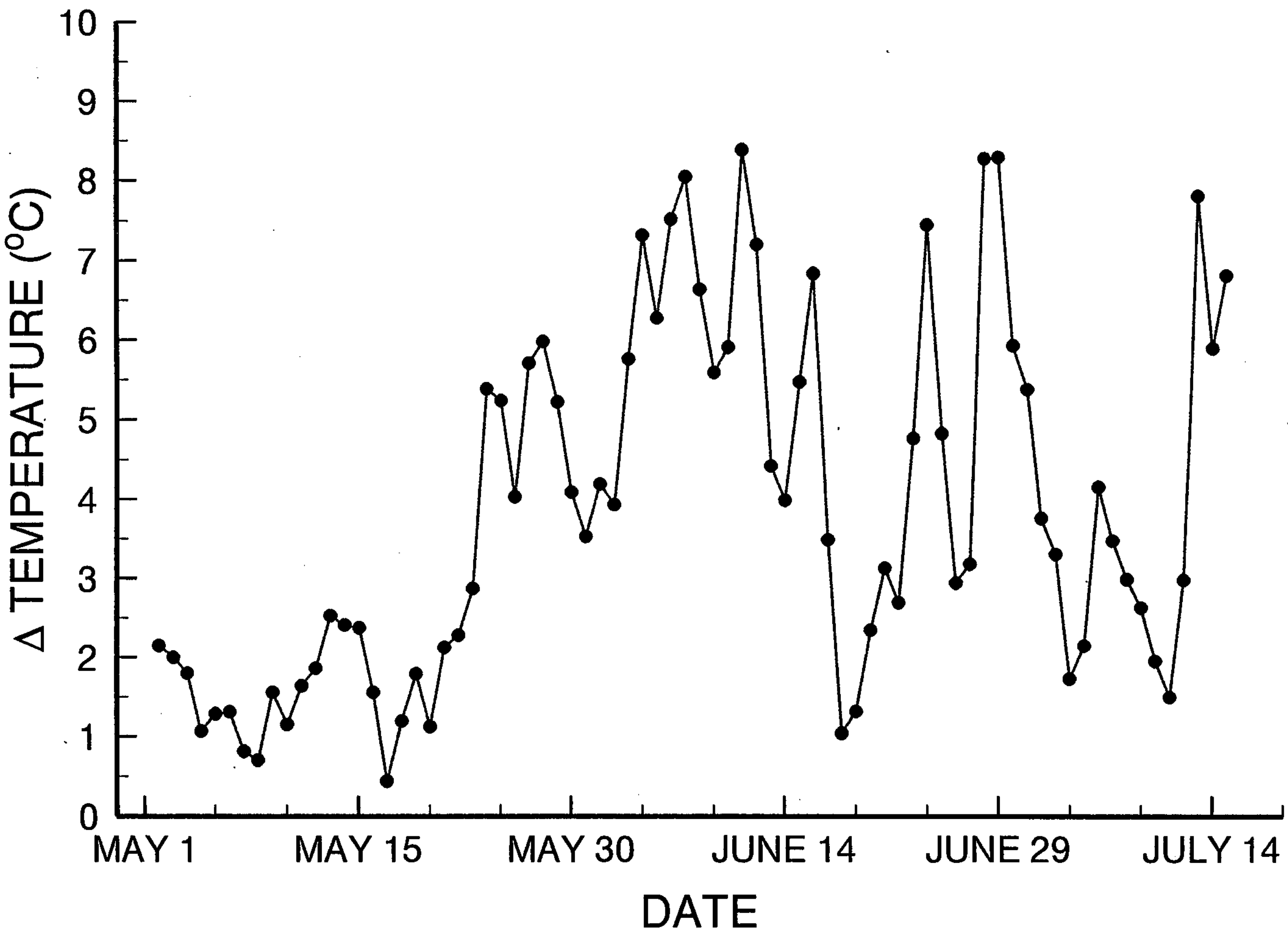

Figure 9. Difference in daily water temperatures between the East River, Chester, and East River Basin, Nova Scotia, 1997.

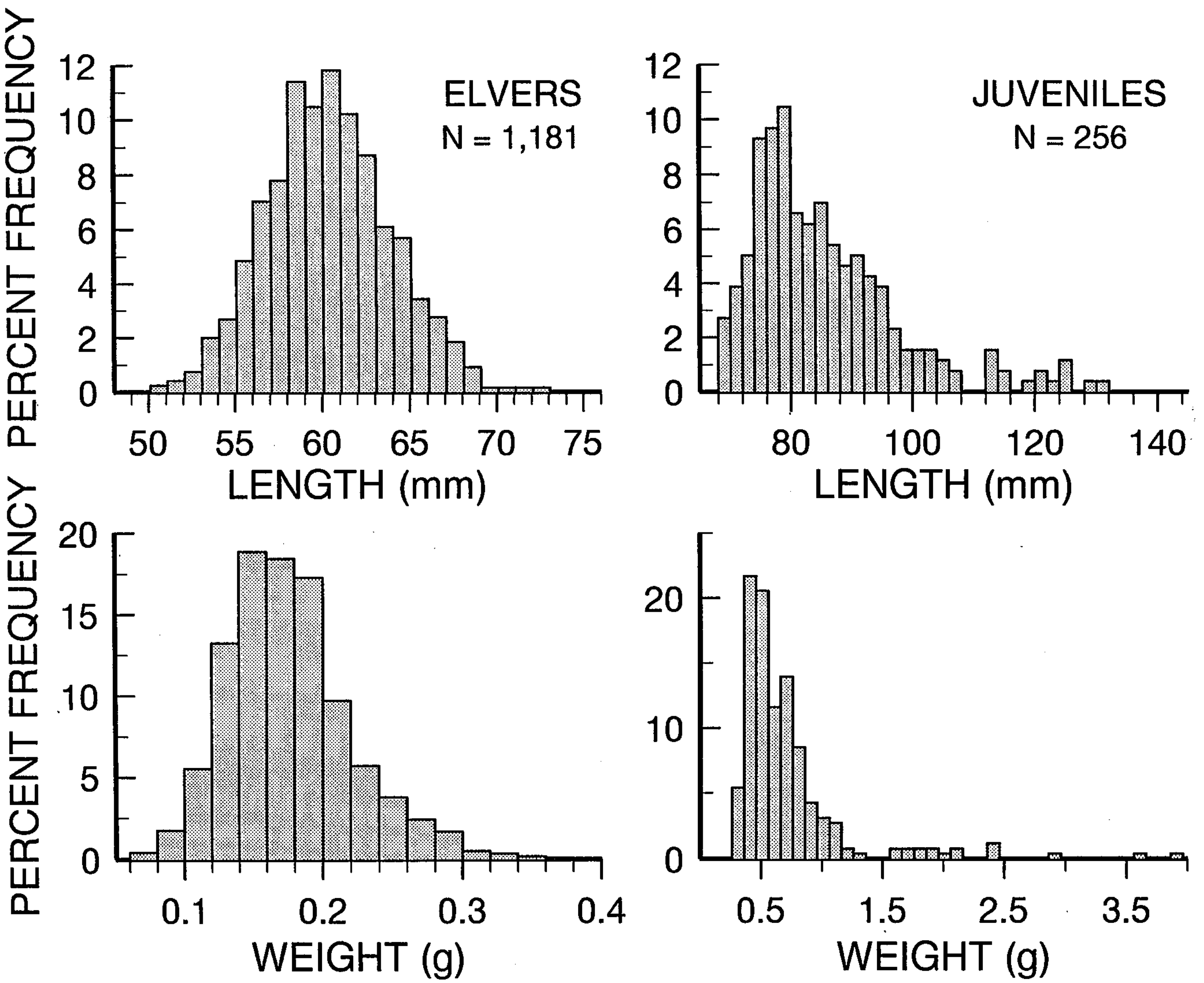

Figure 10. Total lengths and weights of elvers and juvenile American eels from the East River, Chester, Nova Scotia, 1997.

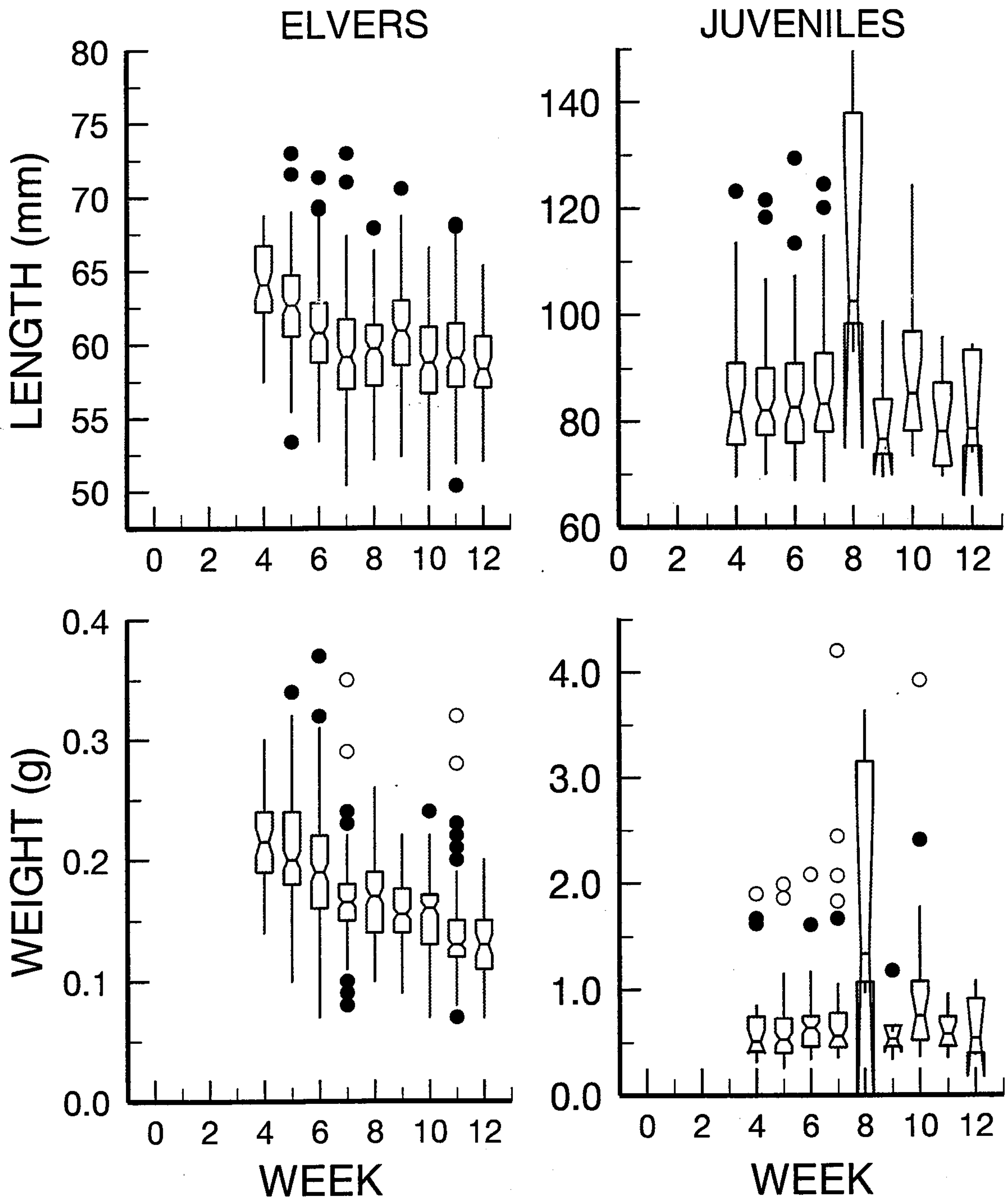

Figure 11. Median and sample distributiion of lengths and weights of elvers and juvenile American eels, by week, from the East River, Chester, Nova Scotia, 1997. The center of the horizontal line marks the median of the sample distribution, the limits of the notches approximate a 95% confidence interval 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 the 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: (4: May 18-24) 50, 23, (5: May 25-31) 180, 78, (6: June 1-7) 240, 68, (7: June 8-14) 210, 41, (8: June 15-21) 150, 5, (9: June 22-28) 160, 6, (10: June 29-July 5) 150, 19, (11: July 6-12) 149, 14, (12: July 13-15) 50, 5.

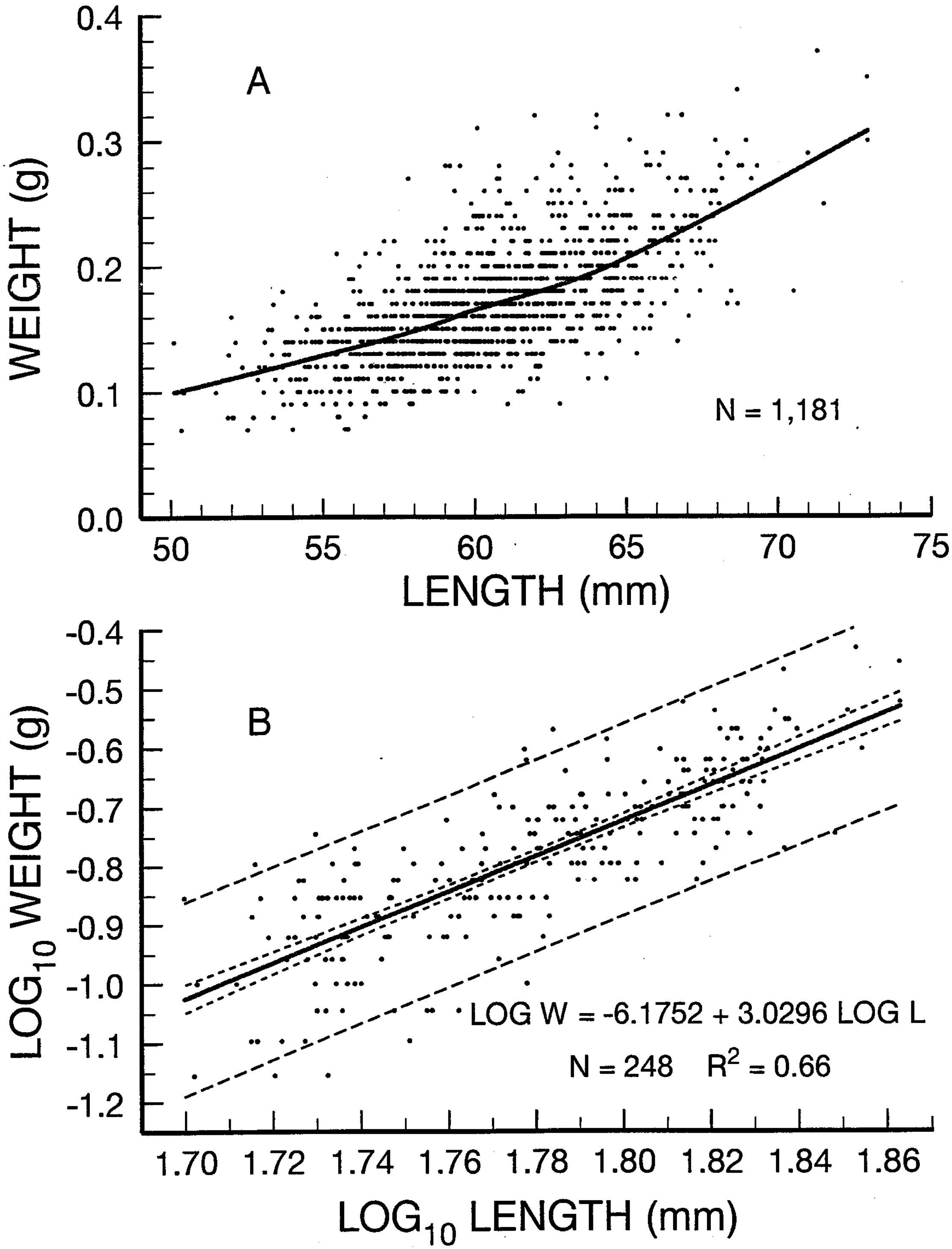

Figure 12. Weight-length distribution of (A) the observed data and (B) logarithmically transformed values of a randomly selected subset of the data, with linear regression equation, 95% confidence limits (short dash) and 95% confidence bounds (wide dash) for American eel elvers from the East River, Chester, Nova Scotia, 1997.

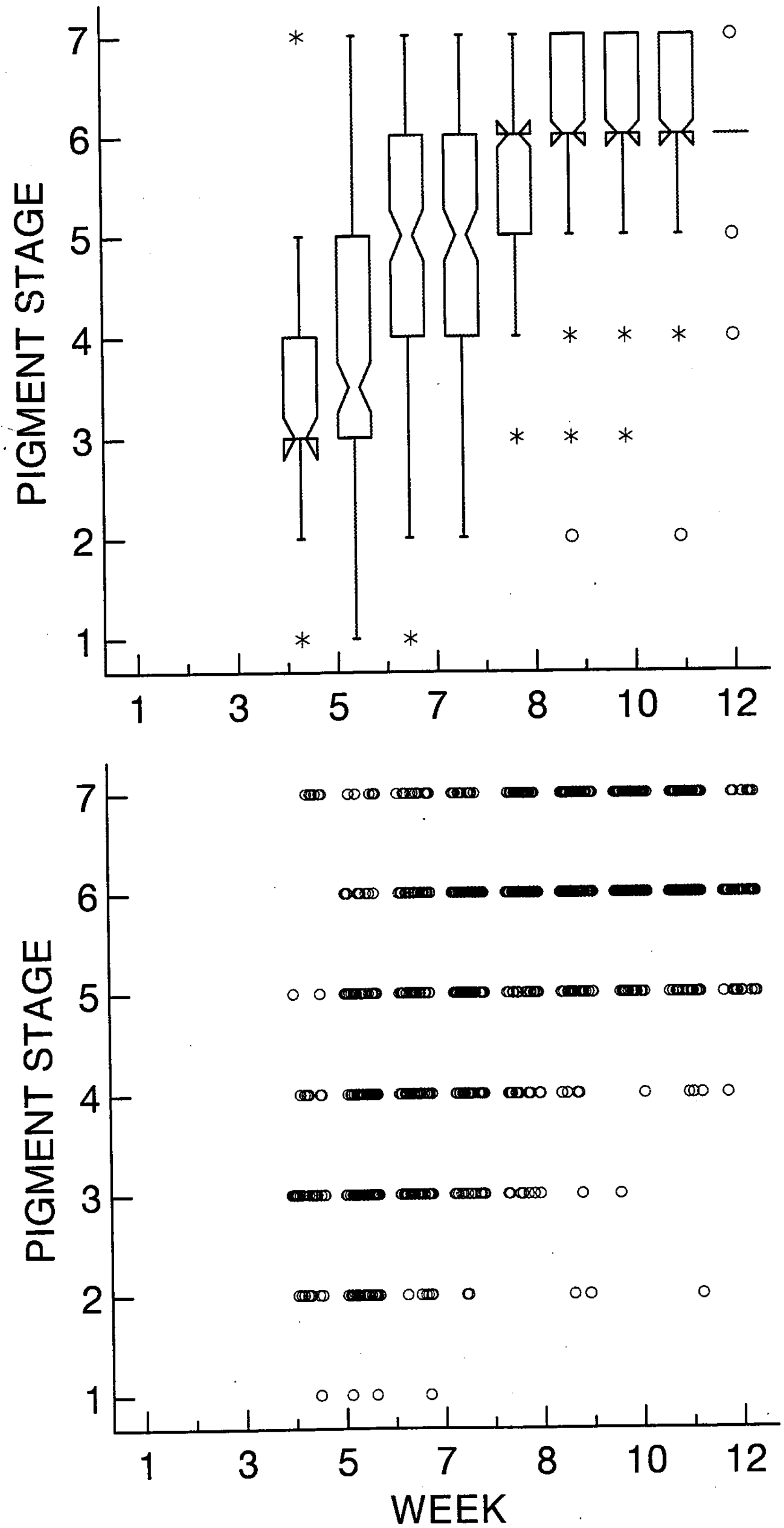

Figure 13. Median and sample distribution (A) and sample density distribution (B), by week, of the pigment stage of American eel elvers from the East River, Chester, Nova Scotia, 1997.