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Abstract

In 2000, American eel elvers were first caught in the estuary of the East River, Chester, Nova Scotia on May 2 when river temperature was about 9°C. The catches from four elver traps situated just downstream of a natural falls were used to estimate the total run size. No commercial dip-net fishery occurred in this river during 2000 due to poor market conditions. A total of 791,200 (95% CI 773,950-808,460) upstream-migrant elvers were caught in the elver traps between April 27 and July 25. A run of 1,202 juvenile eels occurred concurrent with the elver run. Elvers and juvenile eels followed a similar four-wave pattern of run abundance. Elver lengths decreased by 5%, weights decreased by 30%, and pigmentation stage increased from stage 2-3 (glass and lightly pigmented elver) to stage 5-7 (heavily or fully pigmented) between April 30-May 6 and June 25-July 1, the first 9 weeks of the run. Elver condition declined 14.6% over the first 8 weeks of the run, after which signs of growth and increasing condition were evident for some elvers and decreased condition was evident for other elvers.

Elver daily run size was uninfluenced by river water temperature, the difference between river and estuarine water temperatures, or nighttime tide height but tended to decrease with increasing river water level. The effect of various environmental variables were similar in 1997 and 1998 and 1999 and differed from their effect in 1996, indicating that annual conditions play an important but variable role in regulating the upstream movement of elvers. Elvers took about 51 days to migrate 1.325 km upstream, for an average migration rate of 26.0 $m \cdot d^{-1}$.

Mark-recapture estimates of the population size of the elver run were three times larger than the trap count at the river mouth and 2.1 times larger than the trap count at the upriver sites. High mortalities of the marked elvers relative to the unmarked elvers are believed to have inflated the mark-recapture estimates. Based on the trap counts, the finite mortality rate (*M*) for elvers was 0.9921 (95% CI 0.9920-0.9923) and the instantaneous daily mortality rate (*Z*) was 0.1275 (95% CI 0.1269-0.1281).

Resumé

Le 2 mai 2000, lorsque la température de l'eau de la rivière était d'environ 9 °C, on a commencé à capturer des civelles (anguille d'Amérique) dans l'estuaire de la rivière East, à Chester (Nouvelle-Écosse). Nous nous sommes servis des données de captures de quatre pièges à civelles mouillés immédiatement en aval d'une chute naturelle pour estimer la montaison totale. Étant donné la mauvaise conjoncture du marché, aucune pêche commerciale au carrelet n'a été pratiquée dans cette rivière en 2000. Au total, 791 200 (I.C. à 95 % : de 773 950 à 808 460) civelles en montaison ont été capturées dans les pièges entre le 27 avril et le 25 juillet. Une montaison de 1 202 anguilles juvéniles s'est produite en même temps que la montaison de civelles. Les nombres de civelles et d'anguilles juvéniles ont présenté le même régime de montaison en quatre vagues. Durant les neuf premières semaines de la montaison, soit de la semaine du 30 avril au 6 mai à celle du 25 juin au 1^er^ juillet, la longueur et le poids des civelles ont baissé de 5 % et de 30 %, respectivement, et leur pigmentation a augmenté, les civelles passant des stades 2-3 (transparentes ou légèrement pigmentées) aux stades 5-7 (fortement ou complètement pigmentées). Le coefficient de condition des civelles a diminué de 14.6 % durant les huit premières semaines de la montaison, après quoi certaines civelles ont montré des signes de croissance et d'augmentation du coefficient de condition, alors que ce coefficient a baissé chez d'autres civelles.

La température de l'eau de la rivière, la différence entre celle-ci et la température de l'eau de l'estuaire et la hauteur des marées nocturnes n'ont pas influé sur le nombre quotidien de civelles en montaison, mais ce nombre avait tendance à baisser lorsque le niveau de la rivière augmentait. L'effet des diverses variables environnementales a été semblable en 1997, en 1998 et en 1999, mais il différait de l'effet observé en 1996, ce qui montre que les conditions annuelles jouent un rôle important mais variable dans la régulation de la montaison des civelles. Celles-ci ont migré sur 1,325 km vers l'amont en approximativement 51 jours, ce qui correspond à un taux de migration moyen de 26,0 $m \cdot j^{-1}$.

Les estimations par marquage-recapture de la population de civelles en montaison sont trois fois et 2,1 fois plus élevées que les résultats des dénombrements effectués au moyen de pièges à l'embouchure de la rivière et aux sites amont, respectivement. Nous croyons qu'en raison de la forte mortalité des civelles marquées par rapport aux civelles non marquées, les valeurs obtenues par marquage-recapture sont des surestimations. Selon les dénombrements de civelles effectués au moyen des pièges, nous avons calculé que leur taux de mortalité fini (*M*) était de 0,9921 (I.C. à 95 % : de 0,9920 à 0,9923), et leur taux instantané de mortalité quotidienne (*Z*), de 0,1275 (I.C. à 95 % : de 0,1269 à 0,1281).

Introduction

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, no overexploitation of the eel resource occurs either in specific rivers or regionally and that there are no negative effects on the continental stock (Jessop 1995; 1996a; 1996b). Numerous aspects of the biology of American eels and the effects of fishing on them are unknown or uncertain. It has only recently become apparent that Japanese eels *A. japonica* (Tsukamoto et al. 1998; Tsukamoto and Arai 2001) and European eels *A. Anguilla* (Tzeng et al. 2000) may not be strictly catadromous. This may also be true for American eels, which show a variety of estuarine-freshwater migratory patterns (Jessop et al. 2002). The typical decline in elver length and weight during the run that is evident in the Maritime Provinces (Jessop 1998c) may not be evident in more southerly rivers, e.g., North Carolina (Powles and Warlen 2002). 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 remain unknown, although Jessop (2000a) has examined elver fishery exploitation rates and catchability by dip net.

This report analyzes the results of the 2000 study of the run of American eel elvers and juveniles to the East River, Chester, Nova Scotia and examines: (1) the seasonal duration, daily abundance, and size, by direct count and mark-recapture, of the elver run and by direct count of the juvenile eel run, and (2) the seasonal composition of elver and juvenile eel length and weight, and elver pigmentation stage. No commercial dip net fishery for elvers occurred on the East River in 2000 and thus no estimates were made of the efficiency (catch per hour of fishing effort) of the dip-net elver fishery and the rate of exploitation (catch as a proportion of the total elver run) by the fishery. The format and text of previous reports (Jessop 1997; 1998; 1999; 2000b) has been followed where appropriate so as to facilitate comparison of the characteristics of the elver runs to the East River, Chester in the years 1996-2000.

Study Area

The East River, Chester has a watershed area of 134.0 km^2, of which 10.5% is lake surface, and drains into the East River Bay portion of Mahone Bay (Figure 1). It has two tributaries: Barrys 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 that, 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., personal communication). The dominant species, by a factor of at least four, was the American eel, with densities 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.

Two small falls (about 2.4 m high) occur on the main stem about 0.9 and 1.1 km upriver from the mouth. An overpass for Highway 103, consisting of five adjacent 50-m long, 5-m wide, and 4-m high rectangular concrete box culverts, occurs about 1.3 km upstream and forms a seasonal obstruction to upstream eel movement (Jessop 2000).

Methods

Trap Set-up

Four Irish style elver traps (O'Leary 1971) were operated at the mouth of the East River, Chester between April 27 and July 25 (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. the furthest downstream on the true (proceeding downstream) right bank, 2. upstream on the true right bank, 3. downstream on the true left bank, and 4. upstream on the true left bank. Trap sites were selected with the objective of collecting all elvers migrating upstream. The expectation was 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.

Two elver traps were also set up on June 7 at the downstream edge of the box culverts forming the Highway 103 overpass on the main stem of the river, approximately1,325 m upstream from the falls at the river mouth. Water levels prior to May 31 were too high to install the upstream traps earlier. These traps were used primarily for a mark-recapture experiment. Length-weight data on elvers collected at the upstream site on the main river stem are also analyzed. These traps were removed on August 4 and the project terminated due to funding restraints. Previous studies, e.g., Jessop (2000) have indicated that elver and juvenile eel movement to this site may continue until at least late September although with much decreased intensity after late August.

Elver Processing

Elver catches were counted each morning for each trap, with counts of individual elvers when numbers were small (less than about 150 elvers) or by volumetric estimation in approximately 50, 75 or 100 ml aliquots by calibrated graduated cylinder. Other intermediate volumes were sometimes used and adjusted by the 50-ml calibration value because the number of elvers at 100 ml was essentially double that at 50 ml due to the slope of the calibration regression. The graduate cylinder was calibrated twice during the run to account for the known decline in elver size during the run (Haro and Krueger 1988; Jessop 1998c). Between May 6-8 and June 1-3 (early and mid-run), nine calibration counts were made at volumes of 50, 75 and 100 ml. The mean elver counts at the various volumes, as appropriate (early run: 50 ml, 219 elvers, SD = 20.24; 75 ml, 298 elvers, SD = 16.36; 100 ml, 418 elvers, SD = 21.94; late run: 50 ml, 228 elvers, SD = 13.90; 75 ml, 337 elvers, SD = 31.96; 100 ml, 468 elvers, SD = 30.36; N = 9 in all sample groups) were used as the calibration constants for the appropriate run periods. Early and late run mean elver counts at 50 ml were not significantly different ($F_{1,16}$ = 1.1, $P > 0.50$) but were different at higher volumes (e.g., at 75 ml $F_{1,16}$ = 16.7, $P < 0.001$). The linear regression relating elver count (Y) with cylinder volume (X) for the early run period was Y = 3.976X + 13.50 (N = 27, r^2_{adj} = 0.94, $P < 0.0001$) and for the late run period was Y = 4.811X – 16.463 (N = 27, r^2_{adj} = 0.95, $P < 0.0001$).

Procedures for estimating the daily and seasonal total elver catch and 95% confidence intervals (95% CI) for the seasonal total catch were as described in Jessop (2000a, 2003a, 2003b). The total daily elver trap catch for each calibration period was estimated as $Y_d = \sum_i N_i \bar{y} + count$ where Y_d is the total daily catch, N_i is the number of aliquots at the *i*th volume (50, 75, 100 ml), $\bar{y}$ is the mean calibration count at that volume, and *count* is the count of individual elvers (Cochran 1977). The seasonal total trap catch was the sum of the daily trap counts for each calibration period. The variance of the estimated trap catch for each calibration period c was estimated as $S_c^2 = \sum_i \frac{N_i^2 s_i^2}{n_i}$ where N_i is the number of aliquots at the *i*th calibration volume, s_i^2 is the variance of the calibration for that volume, and n_i is the number of counts for that volume (Cochrane 1977). The standard error of the estimated total trap catch $S_T = \sqrt{S_{Y1}^2 + S_{Y2}^2}$ was used to estimate 95% confidence intervals in the standard manner, i.e., total trap catch $\pm t_{0.05,\,df} S_T$. Catches during each calibration period were assumed to be independent.

On Mondays, Wednesdays, and Fridays a representative sample of up to 50 elvers, as available, was killed in 4% formalin then immediately measured for total length (TL, to 0.1 mm) by digital caliper and weighed (to 0.1 g) after blotting dry. All elvers not sampled for biological data were released upriver alive about 75 m from the falls at the river mouth.

Juvenile eels (fully pigmented and/or sizes exceeding 75 mm and 0.35 g) were separated from the elvers, counted and, on Mondays, Wednesdays, and Fridays, 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 and 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 were: 1. 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 in previous years and on similar studies of the elver data from the East River, Sheet Harbour (Jessop, unpublished data). No eels were reclassified as to elver or juvenile, typically from putative elver to juvenile, although twenty-three (1.4%) of all sampled eels (*N* = 1,619) had lengths and weights typical of elvers but pigmentation state typical of juvenile eels. All of these eels were of pigment stage 8 and small size and usually occurred early in the run when other elvers were of low pigmentation stage. Otolith analysis has confirmed that these eels are small juveniles of age-1 (Jessop et al. 2003a).

Habitat Data

Water temperatures (to 0.1 °C) were recorded every hour by thermographs set in the East River upriver (80 m) of the falls at the intake of the NS Department of the Environment pumphouse and at a wharf in the estuary about 0.3 km from the river mouth on April 11 (Figure 2). Another thermograph was set downriver (80 m) of the Highway 103 overpass on April 25. As a proxy for river discharge, river relative water level in the pond upriver of the falls was measured daily by a Global Water (11257 Coloma Rd., Gold River, CA 95670) WL-3 water level logger (to ± 0.2 cm) installed on April 11. 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). A failure of the water level gauge set at the site previously used in East River Bay prevented the use of locally measured tidal heights. The water level and temperature recorders were removed from all sites on August 4.

Near-shore (about 15-30 cm from shore and 10 cm below the surface whenever possible) water velocities were measured with a Global Water FP100 flow probe (to $\pm$ 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 = 0.36, P = 0.04) 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).

River discharge was measured at the Highway 103 center culvert during the period June 27-July 26 when the flow was restricted to the center culvert. Mean depth and water velocity was evaluated three times weekly by measurements at three points equally spaced across the channel width (4.62 m).

The possibility that elvers could bypass the falls at the river mouth was investigated by periodic nighttime (between dusk and midnight) surveys of the shoreline area at and just downstream of the falls. The objective was 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. Between May 7 (when water levels had fallen sufficiently to consider their use) and July 26, a single tube-trap (Tube trap #1) was sited at the shore edge of the true right river bank and just upstream of the falls at the river mouth so as to attempt to estimate the relative magnitude of elver bypass (ascent past) the falls. A second tube trap (Tube trap #3) was set near Tube trap #1 between May 7 and May 24 and a third tube trap (Tube trap #2) was set on the opposite stream bank (true left bank) just upstream of the falls between May 30 and July 25. Tube trap # 4 was set between May 21 and July 3 upriver where the stream enters the upper end of the pond to help evaluate the rate of elver movement upstream.

No commercial dip-net fishing for elvers was conducted in 2000 because of poor market conditions. The elver traps were operated until July 25, when daily catches averaged about 50 elvers or less.

Statistical Analysis

The effects of environmental variables on the start and pattern of elver migration were analyzed, following Jessop (1997; 1998; 1999; 2000; 2003b), 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. This model will be termed the river temperature model.

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 not tested in 2000 because of the lack of water temperature data from the bay. The hypothesis could be 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 2 has been termed the temperature difference model. The environmental analysis was limited to the period May 2-June 24, during which over 99.6% of the elver run occurred.

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 daily mean river water temperatures and decline in water levels between April 14 and June 29 (r = -0.94, $P < 0.0001$, N = 80) 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 daily mean river water level and temperature remained significant (r = -0.33, $P < 0.003$, N = 79).

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. A negative lag adjustment of one day was necessary between daily elver counts and river level and of five days with night tide level. Differenced and appropriately lagged river level and temperature and night tide values were used in the multiple linear regression of elver counts with environmental variables.

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) is uncertain (Neter et al. 1996, p. 516; Wilkinson et al. 1996). Although parsimonious models eliminate non-significant variables and elimination of a non-significant constant produces a no-intercept model, the 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). The constant from the intercept regression model was non-significant (P > 0.90) in all cases and the pattern of variable significance was similar to that produced by the no-intercept model. Consequently, the results from the intercept model are presented, with output from temperature models 1 and 2, with all variables included and with non-significant variables deleted (the "best" model), 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 244 elvers was selected from a total of 1,614 elvers.

Weekly mean lengths and weights ($\log_{10}$ transformed) of elvers were compared by one-way analysis of variance (ANOVA), with multiple pairwise comparisons of means by the Tukey-Kramer HSD method (Wilkinson et al. 1996). Weekly mean elver condition (a measure of well-being) was estimated as the weekly mean weight adjusted to a common (the overall mean) length by ANCOVA (Cone 1989; Springer et al. 1990). Only those weeks meeting the requirement for homogeneous slopes were examined. Mean elver condition was compared among weeks by the Tukey-Kramer multiple comparison test. Weekly plots of the residuals from the annual weight-length regression were used to examine seasonal trends in individual elver condition (Jakob et al. 1996; Sutton et al. 2000; Jessop 2003a).

Elvers from the river mouth traps were marked by tail clip and released about 75 m upstream following procedures in Jessop (2000c). Recoveries of unmarked and tail-clipped elvers at the upstream, Highway 103 culvert traps were used to estimate the elver population size at the river mouth. A second mark-recapture trial using elvers collected at the upriver traps and stained by immersion in a 1:20,000 solution of Bismark Brown Y was used to estimate the run size to the upriver traps. Recoveries of unmarked and stained elvers at the culvert traps were used to estimate the run size to the culvert traps. The population estimates were made by a Bayesian analysis (Gazey and Staley 1986), as described in Jessop (2000c).

Estimates of the finite survival rate (S) and mortality rate (M = 1-S) were made from the trap counts at the river mouth and at the upstream traps and from the modal mark-recapture population estimates at these sites. A 95% CI for the survival estimate based on the population estimates was derived from the appropriate limits of the 95% CI for those population estimates.

Trap count and mark-recapture population estimates at the river mouth and upstream trap site were used to estimate the instantaneous daily mortality rate (Z), where

$$Z = \frac{-(\log_e N_2 - \log_e N_1)}{t_2 - t_1},$$

and N_1 and N_2 are the population sizes at times t_1 and t_2. For the trap-counts, the modes of the run to the river mouth (May 22) and to the upriver traps (June 28) were chosen as t_1 and t_2, for an interval of 38 d. For the mark-recapture data, t_1 and t_2 were chosen as the dates of the modal release of tail-clipped elvers (May 27) and the modal recapture of Bismark Brown Y-marked elvers (July 17), for an interval of 52 d.

Results

Elver Fishery and Run

No commercial elver dipnet fishery was conducted at the East River, Chester, during 2000 because of poor market conditions.

The four elver traps became operational during May 1-4, with elvers first caught on the morning of May 2 (Table 1; Figure 4). A few unpigmented elvers were observed under the bridge at the river mouth on 27 April. Water levels declined irregularly between April 14 and July 26, with major water level rise peaks on April 26, May 12 and May 26 when heavy rainfall raised water levels. The peak of the first of four waves of elvers occurred on May 9, followed by the largest wave peak on May 22 and then by progressively smaller wave peaks on June 2 and June 18 (Figures 4 and 5). The mean time between the three major peaks was 12 d (range 11-13 d), with 16 d to the final peak. Over 95,000 elvers were caught daily during the peak day of the second wave of elvers. Small catches (typically less than 100 elvers) continued after July 1 until project termination on July 25. Fifty percent of the total runs of elvers and juvenile eels occurred by May 22, with over 95% of the run occurring by June 18 for elvers and June 22 for juvenile eels. The total catch by elver trap was estimated as 791,200 (95% CI ± 17,250) elvers. Juvenile eels were first caught on May 2 and, although much less abundant (catch = 1,202 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 May 9, some daytime activity was evident. Daytime activity was of substantially lesser magnitude than at night.

Total and peak elver catches varied among the four traps, from 102,500 elvers in Trap 4 and a peak of about 28,230 elvers to 301,840 elvers with a peak catch of about 59,360 elvers in Trap 2 (Table 1; Figure 6). Traps 2 and 4, the furthest downstream, caught large quantities of elvers earlier in the run than did the traps further upstream while the upstream traps caught elvers later in the run. Peak catches in the downriver traps occurred at the same time or 1 day before peaks in the upriver traps.

The total run of elvers to the East River, Chester was estimated by trap count as 791,200 (95% CI ± 17,250) elvers. Fishing efficiency, or exploitation rate, by dipnetting was not estimated because there was no fishery. The estimates of run size have high precision (< ± 5%) but unaccounted-for elver escapement, which is believed to have been low, would inflate the estimate of the run size.

Elver Instream Movements

Shoreline physical conditions changed with fluctuating water levels and velocities. Water velocity at the river mouth, as expected, was significantly correlated (r = 0.36, P = 0.04, N = 32) with river water level, after differencing. Both water level and velocities were high early in the elver run, fluctuating in response to rainfall events but declined steadily, although irregularly, throughout the run (Figures 4 and 7). Water velocities varied among sites depending upon their physical characteristics, but averaged (all sites) 60.9 $cm \cdot s^{-1}$ between April 30 and May 6, falling to 43.9 $cm \cdot s^{-1}$ between May 28 and June 3, and 23.0 $cm \cdot s^{-1}$ by early July (July 2-8).

No signs were observed of possible elver movement upstream beyond the waterfall or bypassing the traps before early May. During the second week of May, 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. Between May 8 and July 25, the two (sometimes 3) tube-traps at the lip of the falls collected 1,820 elvers (daily range 0-143 elvers). Daily tube-trap and trap counts (non-zero counts, $\log_{10}$-transformed) were highly correlated ($r = 0.57$, $P < 0.001$, $N = 46$). During this period, 92.1% of the elver trap catch occurred; thus, potential elver bypass can be minimally estimated as 0.25% during this period or 0.23% of the total run. Rather than bypass, these elvers may also be recaptures from those released into the pond above the falls. Some elvers may get washed back downstream because marked elvers released to the pond have been recovered downstream of the falls, e.g., one tail-clipped elver recovered on June 23 in trap 4 (see also Jessop 2000). 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. All potential bypass areas were filled in by dirt or cement (elvers actively avoided wet cement) as quickly as they were identified, thereby minimizing potential escapement to the upriver pond. However, continued decreases in water level and velocity required continued vigilance and maintenance, both night and day.

Environmental Effects on Run Timing

Elvers first entered the traps when mean daily water temperatures were about 9.4 °C in the river and the relative river water level was 0.5 m at the gauge site (Figures 4 and 8). Daily water temperatures in the river increased gradually, and with moderate daily variability, throughout the elver run, reaching a peak near the run period maximum in late June. River water levels declined irregularly between April 12 and August 3, but several increases occurred during this period, with an increase of 11 cm peaking on April 26, 14 cm on May 12, and 12 cm on May 26 in response to heavy rainfall (Figure 4).

For the period to May 12, which included the first wave of elvers entering the river, no significant effects on the elver run count were indicated when all environmental variables were included in the multiple linear regression, environmental analysis models (Tables 2 and 4; Figure 4). As the run progressed, only river water temperature showed a significant positive effect ($P < 0.001$) on the daily elver count in the river temperature model. River water temperature was, however, highly negatively correlated with river water level, even after differencing, over the April 14-June 29 period ($r = -0.33$, $P < 0.003$, $N = 79$).

The non-significant variable tidal height and highly collinear variable river water temperature (water temperature is influenced by water level rather than vice versa) were dropped from the temperature model as required by standard statistical procedure. The reduced model, containing only river height, indicated a significant effect of river level on the daily elver count (Table 3). In 2000, the first two elver-run peaks occurred when the maximum night tide (about 2100-0600 h) was falling and the final two run peaks occurred when the tide was rising. Within these daily trends, the hourly tides were generally falling between 1800-2400 h during the first two run peaks and rising during the final two run peaks.

The t-values of Tables 2 and 3 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 = 1,614) of elver lengths was roughly normally distributed, with a mean of 60.14 ± 0.17 mm (95% CI), median of 60.07 mm, and range from 50.4 to 70.5 mm (Figure 9). Elver weights were right skewed, with a mean of 0.147 ± 0.002 g (95% CI), median of 0.140 g, and range from 0.06 to 0.27 g. Mean (median) elver lengths decreased irregularly between weeks 1-9 of the run from 62.00 (62.79) mm to 58.60 (58.65) mm then increased to 59.47 (59.64) mm in week 13. Elver mean (median) weights decreased fairly steadily until week 11, from 0.182 (0.180) g to 0.122 (0.120) g, after which weight increased slightly to 0.141 (0.140) in week 13 (Figure 10). Elvers declined about 3.4 mm (5%) in length and 0.055 g (30%) in weight between early May (April 30 - May 6) and late June (June 25-July 1). Both unusually long elvers and unusually heavy elvers appeared throughout the run but unusually short and light elvers tended to occur early in the run. High length was not necessarily coupled with high weight. Weekly means varied significantly for elver length (F = 17.5, df = 12, 1,601, P < 0.0001) and weight (F = 59.8, df = 12 1,601, P < 0.0001). Means that do not have a letter in common are significantly different from each other:

Week	May 14-20	May 7-13	April 30-May 6	May 21-27	May 28-June 3	June 4-10	June 11-17	July 23-29	June 18-24	July 9-15	July 2-8	July 16-22	June 25-July 1
Sample size	150	100	50	150	150	150	150	39	150	125	150	100	150
Length (mm)	62.19	62.16	62.00	61.15	60.34	60.14	60.12	59.47	59.19	59.12	59.10	59.09	58.60
	z	z	zy	zyx	yxw	xw	xw	xw	wv	wv	wv	wv	v

Week	April 30-May 6	May 7-13	May 14-20	May 21-27	May 28-June 3	June 4-10	June 11-17	July 23-29	June 18-24	June 25-July 1	July 16-22	July 2-8	July 9-15
Sample size	50	100	150	150	150	150	150	39	150	150	100	150	125
Weight (g)	0.182	0.178	0.172	0.166	0.158	0.150	0.143	0.141	0.139	0.127	0.126	0.126	0.122
	z	z	z	zy	yx	xw	wv	wvu	vu	ut	ut	ut	t

Elver weights increased with increasing length in a slightly curvilinear manner over the length range 47-72 mm (Figure 11A). The predictive linear equation describing the relation, based on a randomly selected subset of the data with 50 elvers per 10 mm length interval as available, is:

$$\text{Log}_{10}\,W = -\,6.3582 + 3.1084\,\text{Log}_{10}\,L \qquad N = 244,\ r^2_{adj} = 0.82,\ P < 0.0001$$

where W = weight (g) and L = length (mm) (Figure 11B). The standard errors of and 95% confidence limits (in parentheses) for the regression coefficients are: constant = 0.1664, (-6.6861 to -6.0304); Log_{10} L = 0.0935, (2.9241 to 3.2927).

Condition

The index of weekly mean elver condition declined significantly (14.6%) over the first eight weeks of the run ($F_{7,1041}$ = 26.5, P < 0.0001), from an adjusted mean weight of 0.171 g to 0.146 g. Adjusted mean weights that do not have a letter in common differ significantly. During this period, the overall mean elver length was 60.75 mm.

Week	April 30-May 6	May 7-13	May 21-27	May 28-June 3	May 14-20	June 4-10	June 18-24	June 11-17
Sample size	50	100	150	150	150	150	150	150
Adjusted weight (g)	0.171	0.165	0.161	0.160	0.158	0.152	0.148	0.146
	z	zy	y	y	y	x	xw	w

Between June 25 and July 29 (weeks 9-13), the assumption of homogeneity of regression slopes was not met (for weeks 1-13, $F_{12,1588}$ = 2.24, P = 0.008). Weekly mean lengths and weights reached their lowest values during this period then began to increase (see length and weight table above and Figure 10). The slopes of the weekly weight-length regressions decreased significantly, from a range of 2.606-3.226 during weeks 1-8 and 2.246-2.496 during weeks 9-12, as some elvers began to increase, and others to decline, in weight at the smaller and intermediate lengths (Figure 12). The assumption of equal covariate means (equal mean elver lengths across weeks) was not met ($F_{1,1612}$ = 167.3, P < 0.0001) due to the general decline in weekly mean lengths but the degree of overlap of the length distributions was such that interpretation of the results was not believed to be greatly affected.

Pigmentation

The degree of elver pigmentation increased progressively over the run, with most elvers in pigmentation stages 2-3 during April 30-May 6, stages 2 to 4 by May 14-20, stages 4 to 6 by June 4-10, and primarily stage 7 by July 23-29 (Figure 13A). Pigment stage 1 (glass) elvers were rarely found after the end of May and comprised less than 3% of elvers during the first two weeks of the run (Figure 13B). Glass eels composed about 0.8% of the total trap catch of elvers, the smallest proportion observed in five years of study. On May 10, one elver of pigment stage 1 had a length of 69 mm and weight of 0.25 g. Five elvers of pigment stage 8 and lengths of 62-70 mm and weights of 0.14-0.32 g were observed during the first two weeks of the run when all other elvers were of pigment stage 4 or less, mostly stages 2-3, and were of comparable or smaller lengths and weights. These eels were classified as juveniles based on their pigment stage and comprised 10% of the 48 juvenile eels caught during the first two weeks. Eels of pigment stage 8 and elver size declined in abundance until early June, after which few were seen. Throughout the run, they totaled 37 eels or 10% of the juvenile eels sampled for length and weight; if classified as elvers, they would have comprised 2.2% of sampled elvers.

Juvenile Eel Biological Characteristics

Juvenile eels (pigment stage 8) entered the East River, Chester, concurrent with the elver run and in a similar wave-like temporal pattern (Figure 5). Of the 1,202 juvenile eels caught at the river mouth between May 2 and July 25, 386 were sampled for biological data. These juvenile eels averaged 82.68 ± 1.18 (95% CI) mm TL and ranged from 61.1-161.4 mm TL; weights averaged 0.60 ± 0.04 g (95% CI) and ranged from 0.14-5.32 g. Juvenile eel lengths and weights were right skewed, more so for weight (Figures 9 and 10). Few individuals exceeded 100 mm in length and 1.5 g in weight. A few larger juvenile eels entered the traps throughout the run. Weekly mean lengths and weights of juvenile eels tended, with some variability, to increase slightly (by about 2-4 mm and 0.04-0.10 g) towards the middle of the run (weeks 4-8) then to decline to initial values as the run ended (Figure 10). The smaller juvenile eels were similar in size to the larger elvers, but tended to be heavier at a given length (Figure 14). The weight-length regression based on the randomly selected subset of elvers was similar in slope (ANCOVA test for homogeneous slopes $F_{1,626} = 2.38$, $P < 0.0001$) but significantly different in elevation (length adjusted mean weight) ($F_{1,627} = 296.9$, $P < 0.0001$) from that for the juvenile eels (Figure 14A).

Although there may be times when it is useful to consider elver growth separately from the growth of older juveniles, the difference in weight at length between growth stanzas was small and should not preclude combining both groups to consider growth in a broader context.

	Weight-length regressions ($Log_{10}Weight = a + b*Log_{10}Length$)					
Group	*n*	r^2_{adj}	a	Std. Error	b	Std. Error
Elver	244	0.82	-6.3582	0.16644	3.1084	0.09354
Juvenile	386	0.94	-6.5176	0.08402	3.2623	0.04389
Combined	640	0.96	-7.5320	0.05592	3.7834	0.03001

Conversion to the exponential form of the weight-length equation ($Weight = a*Length^b$) is achieved by taking the antilogarithm of the constant a, e.g., -7.5320 becomes 2.9378 E^{-8} (Figure 14B).

Upstream Elver Run

Elver movement upstream was monitored between June 7 and August 4 with two elver traps sited at the Highway 103 overpass culverts (Site B, Figure 3). The first of a total of 6,218 elvers were caught at the upstream traps on June 23, with the mode of the first wave of elvers occurring on June 28 (Figure 15B). The modal dates of capture of the first wave of elvers at the river mouth (May 9) and at the upstream culverts indicate that elvers took about 51 days to cover a distance of about 1,325 m, for an average movement rate of 26.0 $m \cdot d^{-1}$. Two large waves of elvers occurred before the run began to gradually taper off. The upstream traps were not checked during the weekends, resulting in an accumulation of fish to be counted on Mondays. The daily discharge at the upstream culverts tended to decline over the period June 27-July 26 but the mean discharge was 0.72 $m \cdot s^{-1}$ (SD = 1.40, range 0.45-0.96 $m \cdot s^{-1}$).

At upriver Site B, elver length and weight distributions were approximately normally distributed but juvenile lengths were highly right skewed (Figure 16). Elver mean (table below) and modal (Figure 17) lengths were essentially similar throughout the run although they declined significantly in early July; weights increased irregularly (data values without a letter in common are significantly different):

Week	July 2-8	June 25-July 1	July 9-15	July 23-29	July 16-22
Sample size	50	50	50	100	50
Length (mm)	60.43 z	61.50 zy	62.36 y	62.41 y	63.16 y
Week	June 25-July 1	July 9-15	July 2-8	July 23-29	July 16-22
Sample size	50	50	50	100	50
Weight (g)	0.131 z	0.134 zy	0.145 y	0.168 x	0.184 w

Based on the timing of the first waves of elver abundance at the river mouth (early May) and upstream (late June), the elvers migrating upstream showed essentially no growth in length over this period (62.16 mm mean length versus 61.51 mm, $P > 0.05$) but by mid July, the elvers had grown about 1.0 mm (1.6%). The corresponding mean weights of migrating elvers decreased about 0.05 g (28%) between early May at the river mouth and late June upriver but by late July, upriver elver lengths had increased to the level of early May at the river mouth (Figure 17, table above). Between the week of June 4-10 (mid-point of the observed elver run at the river mouth) and July 30-August 5 (end of the elver samples collected upriver), a 56 day period, elver mean size increased an average of 2.3 mm in length and 0.03 g in weight. The instantaneous daily growth rate of elvers during this period was 0.00029 $mm{\cdot}d^{-1}$ for length and 0.0016 $g{\cdot}d^{-1}$ for weight.

Upstream Juvenile Run

The timing and pattern of juvenile eel movement at the upstream (Site B) traps was similar to that for the elvers (Figure 15A). A total of 12,167 juvenile eels were counted between June 18 and August 4. Most juvenile eels ranged between about 65 and 85 mm TL but the first wave of juvenile eels included a number of larger eels (up to about 240 mm TL) (Figure 16). A few larger eels also occurred during late July and early August. Juvenile eels varied significantly in weekly mean lengths ($F = 6.42$, df = 5,203, $P = 0.00001$) and weights ($F = 6.76$, df = 5,203, $P = 0.00001$), as indicated in the following table, where means without a letter in common are significantly different.

Week	July 2-8	June 25-July 1	July 9-15	July 30-Aug. 5	July 16-22	June 18-24
Sample size	30	29	30	60	30	30
Length (mm)	70.37 z	70.75 z	70.83 z	72.20 z	92.47 y	95.02 y
Week	July 9-15	June 25-July 1	July 30-Aug. 5	July 2-8	June 18-24	July 16-22
Sample size	30	29	60	30	30	30
Weight (g)	0.315 z	0.316 z	0.418 z	0.455 z	1.855 y	1.917 y

Elver Mark-recapture Population Estimates

A total of 31,642 elvers were tail-clipped between May 5 and June 29, of which 31,193 were released (449 or 1.4% mortality). Recoveries between June 23 and August 3 of unmarked and tail-clipped (total 44) elvers at the upstream, Highway 103 culvert traps were used to estimate the elver population size at the river mouth. From first release to first capture, unmarked elvers took 53 days to travel the 1.30 km to the upstream culvert traps (May 2-June 23), as did marked elvers (May 5-June 26), for an average daily migration rate of 24.5 $m{\cdot}d^{-1}$. If the modes of run abundance at initial capture and recapture are used, the movement duration was 49 d, for an average daily migration rate of 26.5 $m{\cdot}d^{-1}$.

The population size of the elver run to the river mouth was estimated by mark-recapture of tail-clipped elvers to be 2,367,000 (mode) or 2,436,000 (median) elvers, with a 95% CI of 1,792,000-3,379,000 elvers (Table 4). Six weekly periods were used in the analysis rather than the 7 periods of marking and recapture because the first recapture period had no marked recaptures and was thus combined with the second recapture period. The modal mark-recapture estimate of the population size at the river mouth was 3.0 times larger than the trap count of 791,200 elvers.

The second mark-recapture trial using elvers stained by immersion in a 1:20,000 solution of Bismark Brown Y was used to estimate the run size to the upriver traps. A total of 1,624 elvers were captured between June 30 and July 19 at the upriver traps and stained, of which 1,614 were released about 100 m downstream of the culverts. Recoveries at the upriver traps between July 13 and August 4 of a total of 158 elvers, both unmarked and stained, were used to estimate the elver population size at the upriver culvert site. The modal and median mark-recapture estimates of the population size running to the upriver culverts was 13,020 elvers, with a 95% CI of 11,260-15,180 elvers. The mark-recapture estimate of the elver run size to the upstream traps was 2.1 times that of the count.

The finite mortality rate (M) for elvers was 0.9921 (95% CI 0.9920-0.9923) based on the elver trap counts and was 0.9945 (95% CI 0.9915-0.9967) based on the mark-recapture population estimates. The instantaneous daily mortality rate (Z) for elvers was 0.1275 (95% CI 0.1269-0.1281) based on the elver trap counts and was 0.1001 (95% CI 0.0918-0.1097) based on the mark-recapture population estimates.

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 1998c; Powles and Warlen 2002). Elver run durations are also longer in southern areas, with most elvers arriving in North Carolina (Powles and Warlen 2002) over about a 20-week period between December and April (recruitment period range of 5.5 months from mid-November to early May). In Atlantic coastal Nova Scotia, most of the elver run occurs over about 9 weeks between late April-early May and late June although small numbers of elvers may continue to enter rivers until mid August (recruitment period range of about 3.5 months) (Jessop 1998b).

Elver migration occurs in three phases: coastal approach, estuarine phase with transition from sea to fresh water, and upstream migration and distribution within the river (Cantrelle 1981). The 2000 elver run to the East River, Chester, as represented by trap catches, began on May 1, which was similar in timing to the runs in 1996, 1998, and 1999 (Jessop 1997, 1998, 1999, 2000b). In 1997, elvers were first caught on May 22 due to the very high water levels caused by periodic heavy rains between May 4-17 and below normal temperatures (river temperatures did not reach 10 °C until May 13). Elvers begin migrating into the upper estuary several weeks prior to their appearance at the lower trap sites in the river mouth, as indicated by the timing of the commercial fishery that has operated most years downstream of the traps.

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). At the time elvers first entered freshwater, river water temperatures averaged 9.7 °C in 1996 (Jessop 1997), 10.9 °C in 1997 (Jessop 1998a), 12.3 °C in 1998, 11.4 °C in 1999, and 9.4 °C in 2000 and were rising quickly. River water levels were high at the start of the run and declined irregularly during the run in all years.

Once migration had begun, the delay between peaks in commercial and trap catches may represent a final period of physiological adjustment or simply the time necessary to move upstream during high water levels. The limited commercial fishery in 1999 made the lag period of 10 d difficult to properly evaluate. The delay in 1998 of 5-7 d between run peaks in the estuarine dipnet fishery and freshwater trap catches reflects water levels that were rising during the first wave and high, but falling, during the second wave (Jessop 1999). A delay of 1-3 d was observed in 1996 and 1997 when river water levels were usually declining (Jessop 1997, 1998). Elver migration occurred at night except during mid-run, when a window of daytime activity occurred before night migration again predominated (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 1997, 1998, 1999, 2000b) 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 2000 estimated run of 0.79 million elvers to the East River, Chester (drainage area = 134 km^2) and run density of 5,905 elvers·km^{-2} of river drainage area was larger than the run of 0.43 million elvers in 1998, 0.45 million elvers in 1999 and 71-53% of the runs of 1.12 million elvers in 1996 and 1.48 million elvers in 1997(Jessop 1997, 1998, 1999, 2000b). Run abundance in the East River, Chester, annually exceeded that to the much larger East River, Sheet Harbour (drainage area = 526 km^2), by a factor or 1.5-4.3 while run densities were higher by a factor of 4.0-17.3. 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 1998b) and in Europe (Moriarty 1990a, 1992).

Unknown, possibly small, portions of the elver migration to Mahone and East River bays become estuarine resident and do not enter a river. The length composition of the annual run of juvenile eels into fresh water concurrent with and subsequent to the elver run indicates that some eels of a given year-class may remain for several years in the estuary before migrating into fresh water. Elvers and juvenile eels may show a complex pattern of estuarine-freshwater migratory behaviours, with some remaining in the estuary for 1-4 years before entering the river (Jessop et al. 2002). The juvenile run into the East River, Chester, has ranged in abundance from 0.07% to 0.15% of the elver run.

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 at the lip of the falls exceeding about 50 cm·sec^{-1} through the major part of the elver 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 minimized any such movement in 2000 and previous years. Water velocities of less than 50 cm·sec^{-1} persisted from week 7 (June 11-17) onward, during which period the elver run was essentially completed. Between May 8 and July 25, a minimum of 1,820 elvers (0.25% of run during the period) was estimated to have bypassed the elver traps and falls. In comparison, the estimated bypass was 0.49% in 1998 and 1.06% in 1999. The higher bypass of elvers in 1999 can be attributed to the unusually low water levels and velocities during that spring. In 1999, the monthly total precipitation at Bridgewater, a site about 36 km southwest of the East River, was 46% of the long-term monthly average for April and was 81% of the average for May. At St. Margaret's Bay, a site about 23 km northeast of the East River, the total precipitation for April was 63% of the long-term average April precipitation and in May was 61% of the long-term monthly average (Atmospheric Environment Service, Halifax, N.S.). High water velocities throughout the elver runs in 1996, 1997 are believed to have provided effective velocity barriers (Jessop 1997, 1998). 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 dip-netting a specific area may have a large effect (Cantrelle 1981). The absence of a fishery in 1999 and 2000 because of the collapse of the elver market prevented the estimation of a dipnet fishery exploitation rate. The dipnet fishery exploitation rate of 51.8% in 1998 was much higher than in 1996 (30.8%; Jessop 1997) and 1997 (32.1%; 1998a), suggesting that exploitation rate in an intensive fishery may increase when the run size declines. Nonetheless, elver exploitation rates of 30-60% 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. This may be particularly true of acid stressed rivers, such as the East River, where elver mortality rates during the first summer may exceed 99.5% (Jessop 2000). 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 the summer of 2000 was quicker than in 1998 but slower than in 1997 and 1999. Elvers took about 7 weeks (from May 9 to June 28 based on run modes) and averaged 26.0 $m \cdot d^{-1}$ to migrate the first 1.325 km upstream. The two falls on the route were less of a barrier at the relatively low water levels and velocities encountered than in years when water velocities were higher. Elvers migrated the same distance at an average of 32 $m \cdot d^{-1}$ in 1997, 15.3 $m \cdot d^{-1}$ in 1998, and 38.2 $m \cdot d^{-1}$ in 1999 (Jessop 1998a, 1999, 2000b).

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 $m \cdot d^{-1}$ 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). 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 between April 1 and July 1 of about 2.4 $km \cdot d^{-1}$. Elver migration in the Saint John River is enhanced by selective tidal stream transport (McCleave and Kleckner 1982; McCleave and Wippelhauser 1987) because the river is tidal up to about Fredericton (river kilometer 120).

Man-made as well as natural barriers may hinder elver migration upstream. In years when water levels are low during the period when elvers have reached the Highway 103 culverts, such as 1998-2000 but believed to be most years, the culverts may become a total barrier to further upstream movement until rainfall raises the water level such that the side culverts (which have low head dams at their upper ends) begin flowing at a minimal level. Minimal flows in the side culverts permit elvers to move through the culverts; higher flows become a velocity barrier while lower flows dry the side culverts and create a total barrier. The central culvert is a velocity barrier at all flow levels. In low pH, low biological production streams such as the East River, elvers could experience higher first year mortality rates due to density-dependent competition or to increased predation as they gather below obstructions. Upstream migration may consist primarily of elvers and juvenile eels able to move through the culvert system on an opportunistic basis as water levels and velocities permit.

Elvers entered the river in large numbers only after mean river temperatures reached 10 °C in both 1996 and 1997, 12 °C in 1998, and 11 °C in 1999 and 2000. These temperature values are 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 upstream migration in 2000, their abundance and seasonal pattern of movement was significantly influenced only by river temperature and not by river level or nighttime tide height. However, tidal conditions must have played some role because of the observation that elver run peaks usually occurred during periods just before or after peak nighttime tide heights.

The significant effect on American elver migration of river temperatures through all of the 1999 (Jessop 2000) and 2000 runs, most of the 1996 run (Jessop 1997) and much of the 1998 run and absence of a temperature effect in 1997 (Jessop 1998a) differs from observations in other studies. Martin (1995) 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. Such a preference would be consistent with the observed temperature effect in 1996, 1998, 1999 and 2000 but does not account for the absence of a temperature effect in 1997.

The collinearity of water temperature and level confounds interpretation of the specific effects of each variable since the stated significance of the correlated variables may be spurious (Neter et al. 1996). Water temperatures decreased with increasing water level in all years (Jessop 1997, 1998, 1999, 2000) even after detrending by differencing. In 1997, only high water discharge affected trap catches, unlike in 1996 and 1998 when both variables decreased trap catch. In 1999 and 2000, only river temperature was significant in the full model but water level was significant after accounting for the collinearity of water temperature and level. In all years, only water level was consistently significant after accounting for collinearity with water temperature. 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 and 1998 water levels steadily declined (maximum rise of 0.03 m) during the run. In 1999 and 2000, water levels increased just before declining or low elver catches occurred. Even slight increases in water level were sufficient to delay elver upstream movement by several days, resulting in an accumulation of elvers and a subsequent pulse of movement upstream when water levels again declined.

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. In 1996, the significant positive effect on elver daily abundance by water level during the main part of the run when water temperature was not included resulted from the 4 d lag of water level. When smaller lags are used, it is apparent that daily elver count declines with increasing water level, as was found in all other years. 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, i.e., low gradient, no relation between rainfall (discharge, river height) and elver abundance may be typical (Jellyman 1977, 1979; Sorensen and Bianchini 1986) although a relation has sometimes been found (Jellyman and Ryan 1983).

The timing and identity of the environmental effects (river and bay water temperature, river discharge, and tidal phase) varied greatly in their statistical significance in the river temperature and temperature difference models relative to their effect on elver daily run abundance. Although not examined in 2000, no significant effect on the elver run was found for the difference between river and bay water temperature in any previous year (Jessop 1997, 1998, 1999, 2000). 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 (Jessop 2003b).

In 2000, only river water temperature significantly affected daily run size, beginning mid-way through the run. After dropping river water temperature as collinear with river height (discharge), river height became the significant effect. In 1999, river temperature became a significant effect in the river temperature model earlier than did river height in the temperature difference model. When the reduced temperature model and the temperature difference model were compared, there was no difference in when river height became significant. In 1997 and 1998, no difference occurred between regression models in the dates at which environmental effects became significant, except that in 1998, the date at which river level became significant was advanced to June 6 from June 19 when both river level and water temperature were considered together. 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-high 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, 1998, 1999 and 2000 (Jessop 1998a, 1999, 2000, this study), 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 to hold position on the bottom (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, daily trap counts increased concurrently with a rising tide for waves 1 and 3 and declined for waves 2 and 4 (Jessop 1997). 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, while in 1998, five of six run peaks occurred during this time period. In 1999, all three major peaks of the elver run occurred with tides rising to some degree between 1600-2400 h. In 2000, the first two run peaks occurred during a period of falling tides between 1800-2400 h while the last two run peaks occurred during a period of rising tides. 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 appear to influence the elver run in any given year. Water level (discharge or more specifically, velocity) seems to be the primary environmental influence on the progress of the elver run while water temperature provides more of a gating effect for the start of the run rather than influencing the run after it has begun. Tidal effects seem to be sufficiently weak that they are only periodically influential once elvers have reached the head of tide but they clearly play a major role in bringing elvers to the head of tide. The wide variability in site conditions and study design and analysis noted by Martin (1995) may account for the varying results of other studies on the effects of environmental factors on elver runs. Jessop (2003b) concluded that increasing tidal height delivers increasing quantities of elvers, relative to their availability in the estuary, while river temperature acts initially as a gating factor to the start of upstream movement, and river discharge (velocity) controls the subsequent rate of upstream movement.

Both length and weight of American elvers from the East River, Chester, declined slowly throughout the run in 1996, 1997 and 1998 (Jessop 1997,1998, 1999) but increased slightly towards the end of the run in 1999 (Jessop 2000b) and 2000. The relatively greater decline in weight over the elver run than in length results in a concomitant decline in elver condition (Jessop 1998c). The declining trend in length may not be so evident in some years, such as 1998 or when mean length increases during the start of the run, as in 1996. When elver length increases near the end of the run as in 1999 and 2000, elvers have presumably begun growing in response to feeding. Vladykov (1970) and Haro and Krueger (1988) reported declines in elver length during the migratory period but Hutchison (1981) found little change over two weeks. Groom (1975) and Hutchison (1981) noted weight declines. A comprehensive study of changes in the seasonal length, weight, condition and pigmentation of elvers from several Scotia-Fundy rivers is given by Jessop (1998c). 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 length and weight of later arriving elvers may result from beginning metamorphosis further offshore or may simply be determined by leptocephalus size at the start of metamorphosis, with smaller eels perhaps migrating more slowly than larger eels. In either case, smaller elvers would be expected to have greater age before estuarial arrival (Jellyman 1977; Jessop 1998c). Powles and Warlen (2002) have concluded that, based on the age within the glass eel growth zone of the otolith, the smaller elvers are older than the larger elvers and that the smaller elvers take longer to cross the continental shelf.

The biological implications of seasonally decreasing elver length, weight, and condition (Jessop 1998c) 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). There is as yet little or no evidence that seasonal declines in elver length, weight, and condition influence the rate of elver survival although it may be hypothesized that late arriving, smaller elvers experience a higher rate of mortality. At older ages, the annual mortality rate of eels does decline with increasing age and size (De Leo and Gatto 1995). In low pH rivers such as the East River, elver mortality over the first summer in freshwater may be more than 99% (Jessop 2000; this study). The increased variance of the residual index of elver condition later in the run may result from both a resumption of growth by some elvers and starvation and potential mortality by others (Jessop 2003a).

The curvilinear increase in weight with increasing length over the 50-73 mm observed length range varies slightly among years, being less pronounced in 2000 than in 1996 and 1997 and similar to that in 1998 and 1999 (Jessop 1997, 1998, 1999, 2000). Elver weight-length relations typically become markedly curvilinear during the first year of growth (Peterson and Martin-Robichaud 1994) and have noticeable curvilinearity for larger eels (Tesch 1977). The significant difference in weight-length relationships between elvers and juvenile eels suggests that the elvers should be considered a growth stanza different from that of the juveniles. Some of the smallest juveniles have weight-length characteristics similar to elvers.

The seasonal pattern of increase in elver pigmentation over the run also varies among years. The pigmentation rate was roughly similar in 2000 to that in 1999, 1998 and 1996 but less rapid than in 1997 (Jessop 1997, 1998, 1999, 2000). The rapid increase in elver pigmentation in 1997 was perhaps due to the delayed entry of elvers in that year. Pigmentation stage reflects the degree of completion of 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 may increase, 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 eels found early in the run with high pigmentation stage and lengths and weights typical of elvers are small juveniles (Jessop et al. 2002).

Instantaneous daily growth rates (G) for elvers tend to be low or even negative for length and weight early in the run and to increase markedly later in the run. This effect is due to the interaction between declining elver lengths and weights during the run into the river mouth and the slow growth of elvers in fresh water until the growth rate increases later in the run. In 2000, the observed run period was shorter (May-early August) than in previous years and the instantaneous growth rate for length of 0.00029 $mm \cdot d^{-1}$ was less than in previous years with a longer observed growth period, although the growth rate for weight was similar to that in 1999. In 1999, instantaneous daily growth rates for elvers were much lower, even negative for weight, during the early part of the run than during the latter part of the run. When measured over the May-September run period, the instantaneous daily growth rates for elvers in the East River during 1999 were lower than in 1998 (G_{length} = 0.00047 mm·d^{-1} in 1999 versus 0.00107 mm·d^{-1} in 1998; G_{weight} = 0.00142 g·d^{-1} in 1999 versus 0.00469 g·d^{-1}in 1998). The seasonal instantaneous daily growth rates in weight were 3-19% of the daily growth rates in weight observed by Peterson and Martin-Robichaud (1994) for frequently fed elvers reared over a 30 d period in a laboratory at water temperatures of 20-22 °C. Mean water temperatures in the East River during the measurement period averaged 16.9 °C (range 9.0-23.0 °C) in 2000, 20.7 °C (range 14.0-25.1 °C) in 1999 and 19.5 °C (range 14.9-23.3 °C) in 1998. The difference between laboratory and river water temperatures seems insufficient to account for the difference in growth rates. Although the time series is short, there appears no obvious correlation between mean seasonal water temperatures and instantaneous growth rates. The mean lengths and weights of elvers at the start of the growth period were slightly higher in the East River (61.0-62.0 mm, 0.18 g) than in the laboratory (57.1-59.1 mm, 0.145-0.155 g), possibly because of geographic variation in elver size or collection of the laboratory elvers relatively later in the run. The effect of initial elver size on subsequent growth rate is uncertain although the smaller American eel elver grows, under similar conditions, at a higher rate than does the larger European elver so that after several months, they are of similar size (Appelbaum et al. 1998). Thus, the low growth rates in the East River may largely be due to the increased physiological stress of inhabiting low pH waters and the lower productivity of low pH waters (Haines 1981; Forsberg 1986; Wickstrom et al. 1996).

Mark-recapture estimates of the run size of American eel elvers to mouth of the East River, Chester, and to the upstream culverts are typically much higher than by trap count (at the river mouth, 4.6x in 1998, 10.1x in 1999, and 3.0x in 2000; at the upstream culverts, 2.5x in 1998, 10.3x in 1999, and 2.1x in 2000). The trap counts provide the most accurate estimate, most likely because of a high post-release marking mortality (Jessop 2000a). Elvers experience high natural mortality during their first summer in the East River, Chester, with relatively little annual variability observed to date. Finite mortality rates (*M*) by trap count annually varied from 0.9945 in 1998 to 0.9887 in 1999 and 0.9921 in 2000 and by mark-recapture experiment from 0.9968 in 1998 to 0.9885 in 1999 and 0.9945 in 2000 (Jessop 1999, 2000a). High mortality for unmarked elvers was attributed to the effects of low pH (4.7-5.0), high initial elver density (4.7 elvers·m^{2}), and predation by resident eels (Jessop 2000a). Elver fisheries may be particularly justified where the natural mortality rate for elvers is high, as in low pH streams (Jessop 2000a) and where a substantial proportion of the instream population and of silver eel production derives from juvenile eels that have entered from the estuary (Jessop et al. 2002).

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Table 1. Estimated[a] trap catches of American eel elvers and juveniles, by date, from the East River, Chester, 2000. There was no commercial fishery.

	Trap Number					
Date	1	2	3	4	Total	Juvenile
April 27	-	-	-	-	-	-
April 28	-	-	-	-	-	-
April 29	-	-	-	-	-	-
April 30	-	-	-	-	-	-
May 1	-	-	-	0	0	0
May 2	-	0	-	4	4	1
May 3	-	0	0	0	0	0
May 4	-	0	309	2	311	1
May 5	0	63	1,307	2	1,372	13
May 6	1	4,044	11,522	759	16,326	48
May 7	815	6,691	18,781	8,669	34,956	70
May 8	59	754	7,802	1,336	9,951	30
May 9	815	11,622	2,907	28,225	43,569	54
May 10	5	115	2,382	34	2,536	6
May 11	1	8	27	12	48	2
May 12	0	0	0	0	0	0
May 13	-	-	-	-	-	-
May 14	105	879	596	39	1,619	6
May 15	69	1,363	232	132	1,796	13
May 16	234	4,172	6,541	1,489	12,436	24
May 17	1,332	11,411	5,018	32	17,793	32
May 18	1,210	16,513	3,992	10,034	31,749	56
May 19	4,241	11,756	26,135	10,088	52,220	52
May 20	23,408	8,997	6,071	14,092	52,568	71
May 21	15,267	26,844	17,775	1,489	61,375	66
May 22	15,279	59,356	17,209	3,563	95,407	83
May 23	881	40,765	24,273	10,042	75,961	57
May 24	1,891	10,032	13,819	1,932	27,674	43
May 25	150	9,901	19,745	5,245	35041	47
May 26	7	1,689	3,048	424	5,168	20
May 27	27	1,814	2,601	520	4,962	13
May 28	44	1,708	893	918	3,563	6
May 29	24	596	658	78	1,356	11
May 30	127	2,352	4,487	136	7,102	5
May 31	472	3,426	6,253	25	10,176	13
June 1	809	4,413	6,761	7	11,990	32
June 2	20,959	8,441	14,770	350	44,520	39
June 3	4,493	7,576	13,838	198	26,105	38
June 4	2,210	5,969	6,374	7	14,560	13
June 5	5,302	3,741	6,972	44	16,059	32
June 6	397	6,407	5,623	337	12,764	19
June 7	280	1,061	1,349	21	2,711	11
June 8	66	61	58	18	203	0
June 9	100	204	100	5	409	2
June 10	159	385	909	17	1,470	5
June 11	54	603	755	18	1,430	4
June 12	1	91	44	4	140	0
June 13	2	175	0	4	181	0
June 14	2	168	49	4	223	1
June 15	4	228	89	7	328	2
June 16	55	244	2,023	4	2,326	6
June 17	524	4,769	1,176	154	6,623	13
June 18	611	10,370	2,137	697	13,815	37
June 19	565	5,960	6,177	484	13,186	27
June 20	117	1,914	4,384	121	6,536	9
June 21	116	1,023	902	108	2,149	5
June 22	72	0	1,822	82	1,976	7
June 23	30	90	727	74	921	6
June 24	-	-	-	-	-	-
June 25	-	-	-	-	-	-
June 26	13	236	925	61	1,235	10
June 27	21	94	73	46	234	0
June 28	43	74	300	30	447	11
June 29	29	96	50	24	199	0
June 30	25	47	39	26	137	1
July 1	-	-	-	-	-	-
July 2	-	-	-	-	-	-
July 3	29	69	86	15	199	2
July 4	30	39	16	13	98	3

July 5	23	50	11	32	116	2
July 6	14	45	31	14	104	1
July 7	12	31	15	9	67	1
July 8	-	-	-	-	-	-
July 9	-	-	-	-	-	-
July 10	0	71	95	34	200	2
July 11	6	13	15	16	50	1
July 12	6	11	15	9	41	0
July 13	0	18	9	3	30	0
July 14	4	19	2	9	34	0
July 15	-	-	-	-	-	-
July 16	-	-	-	-	-	-
July 17	3	74	45	44	166	5
July 18	2	29	20	5	56	2
July 19	1	10	7	6	24	0
July 20	0	14	9	7	30	2
July 21	3	11	7	4	25	3
July 22	-	-	-	-	-	-
July 23	-	-	-	-	-	-
July 24	1	19	11	8	39	3
July 25	0	4	3	2	9	2
Total	103,660	301,840	283,210	102,500	791,200	1,202

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

Table 2. *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 (logarithm base 10 transformed and differenced) from the East River, Chester, 2000; B_0 = intercept; B_i = coefficient for each parameter; T = daily mean river water temperature (°C, differenced); H = daily river gauge height (level (m), differenced and lagged 1 day); M = maximum tide height for the night preceding the elver count (m, differenced and lagged 5 days).

	t-Values (Probability)					
Date	River temperature	River height	Tide height	df	R^2	*P*
May 12	1.76 (0.12)	-1.59 (0.16)	-0.43 (0.68)	3,6	0.34	0.15
May 29	2.13 (0.04)	-1.71 (0.10)	-0.90 (0.38)	3,23	0.22	0.03
June 8	3.27 (0.002)	-1.41 (0.17)	-0.40 (0.69)	3,33	0.27	<0.004
June 24	4.01 (0.002)	-1.52 (0.13)	-1.20 (0.23)	3,49	0.28	<0.001

Table 3. *t*-Values and their significance, adjusted multiple R^2 values, degrees of freedom (df), and regression significance (P) for parameters of the reduced regression model $E = B_0 + B_1 H$ where E = daily elver trap total count (logarithm base 10 transformed and differenced) from the East River, Chester, 2000; B_0 = intercept; B_i = coefficient for each parameter; H = daily river gauge height (level(m), differenced and lagged 1 day).

	t-Values			
Date	River height	df	R^2	*P*
May 12	-1.95	1,8	0.24	0.087
May 29	-1.99	1,25	0.10	0.057
June 8	-2.13	1,35	0.09	0.040
June 24	-2.21	1,51	0.07	0.031

Table 4. Number of American eel elvers marked (M_t) by tail clip and Bismark Brown Y immersion staining, captured as marked and unmarked (C_t), and recaptured as marked fish (R_t), by sample period, in the East River, Chester, in 2000.

Release period	M_t	Recapture period	C_t	R_t
		Tail clip		
May 5-12	4,630	June 18-23	3	0
May 14-18	4,854	June 26-30	2,404	12
May 24-26	5,929	July 3-7	1,827	10
May 27-June 1	5,160	July 10-14	737	7
June 3-9	5,631	July 17-21	574	6
June 12-14	2,616	July 24-28	267	2
June 20-29	2,373	July 31-Aug 4	450	4
Total	31,193		6,262	44
		Bismark Brown Y		
June 29-30	279	July 10-14	744	17
July 4-5	791	July 17-21	631	63
July 12	174	July 24-28	284	19
July 19	370	July 31-Aug 4	505	59
Total	1,614		2,164	158

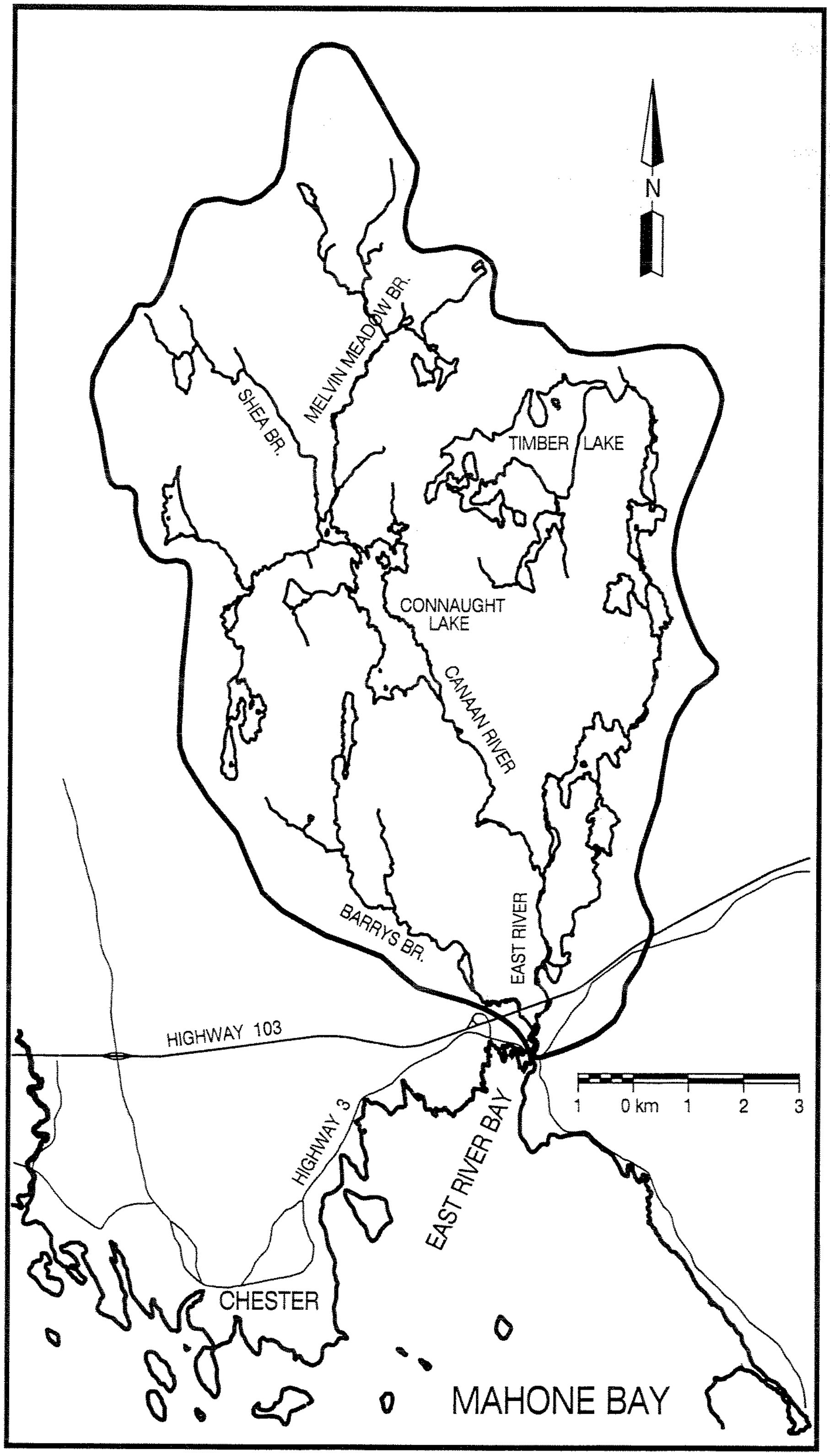

Figure 1. Drainage basin of the East River, Chester, Nova Scotia (area 134.0 km^2).

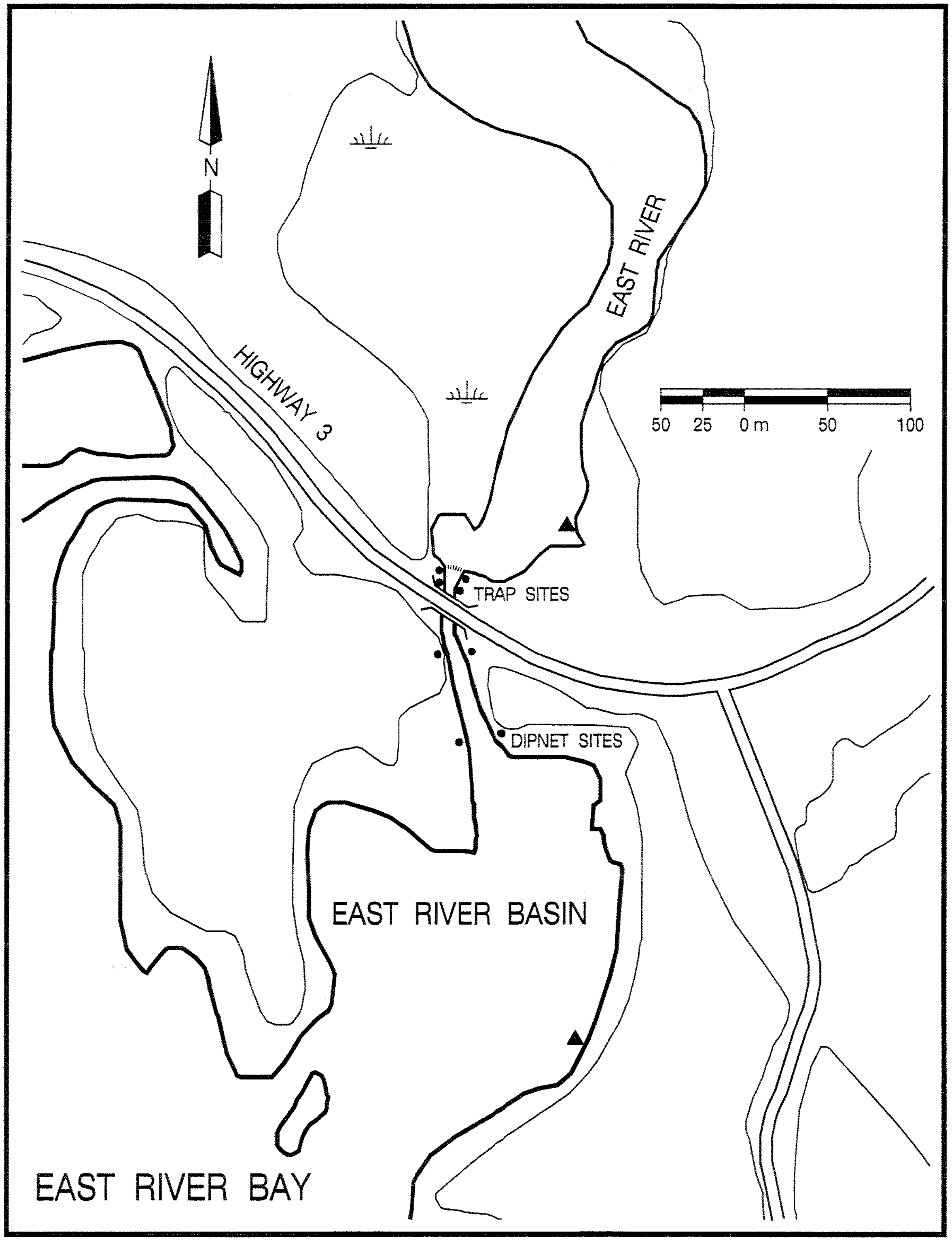

Figure 2. Elver trap and range of dip net fishing locations on the East River, Chester, Nova Scotia. Solid triangles indicate thermograph sites.

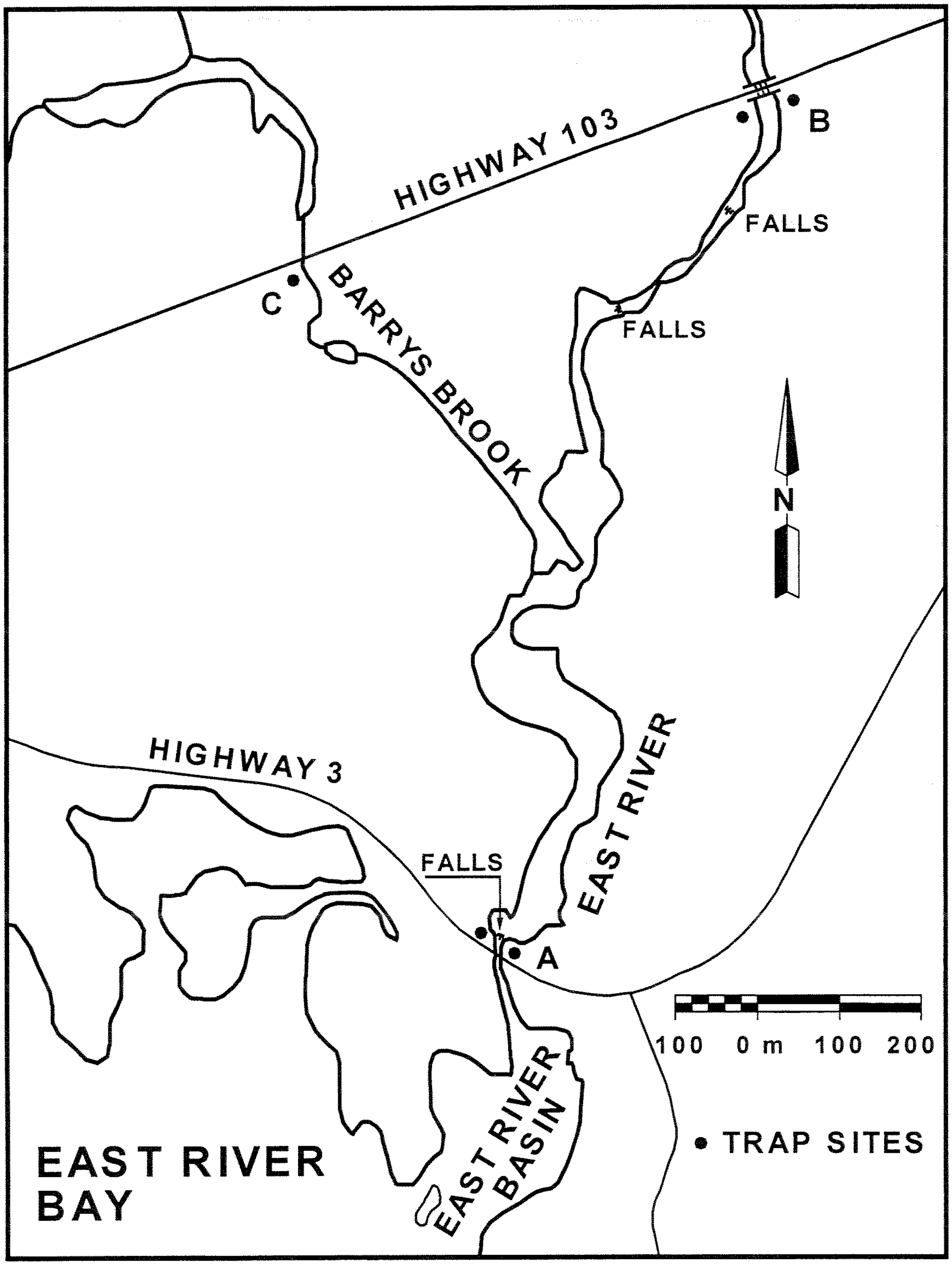

Figure 3. Elver trap sites in the East River, Chester, Nova Scotia, 2000. Site A was the capture site and site B was the recapture site for the mark-recapture experiment. Site C was not used in 2000.

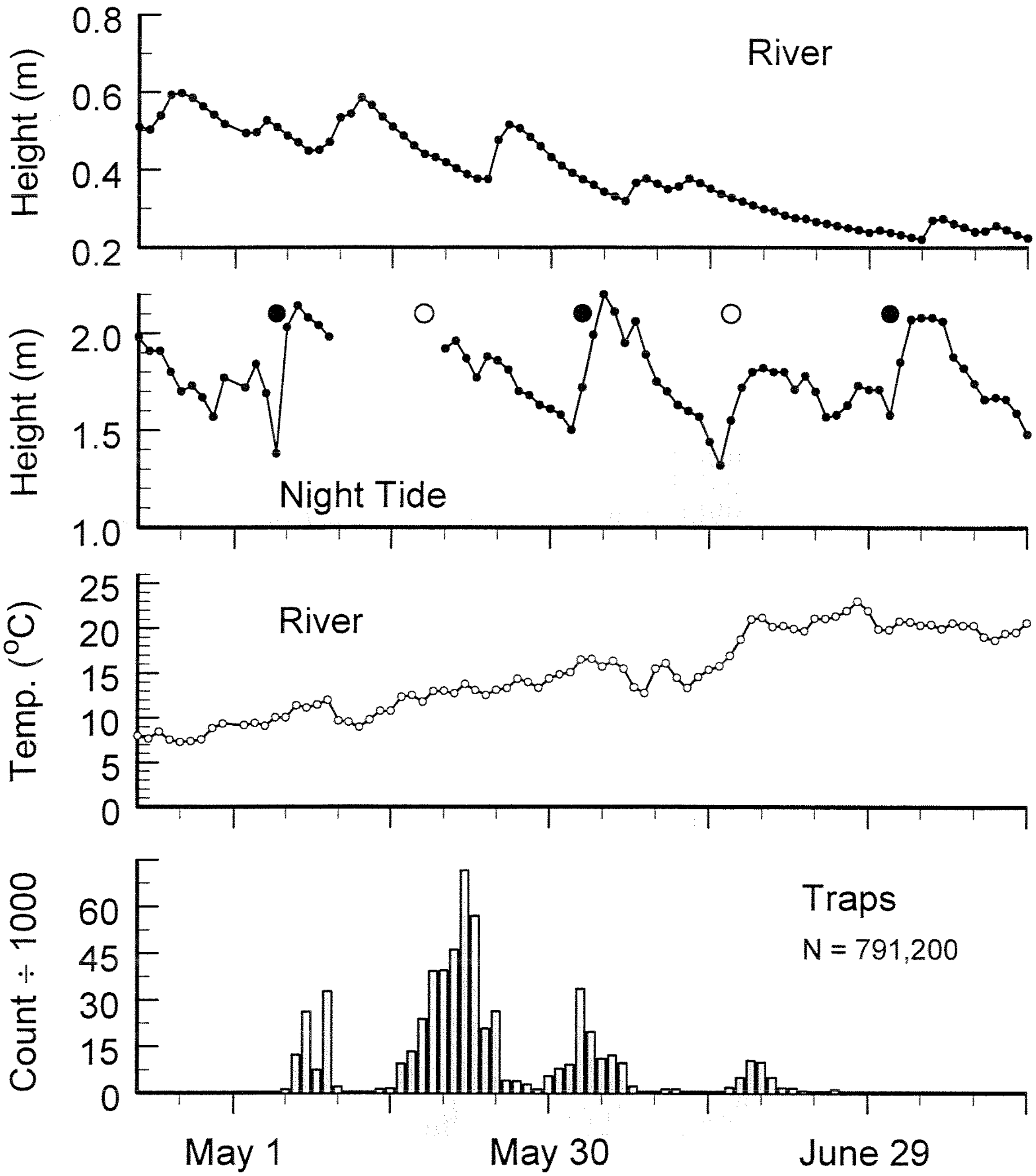

Figure 4. Daily river water levels, nighttime tide heights, river water temperatures, and elver trap counts for the East River, Chester, Nova Scotia, 2000. There was no commercial fishery in 2000.

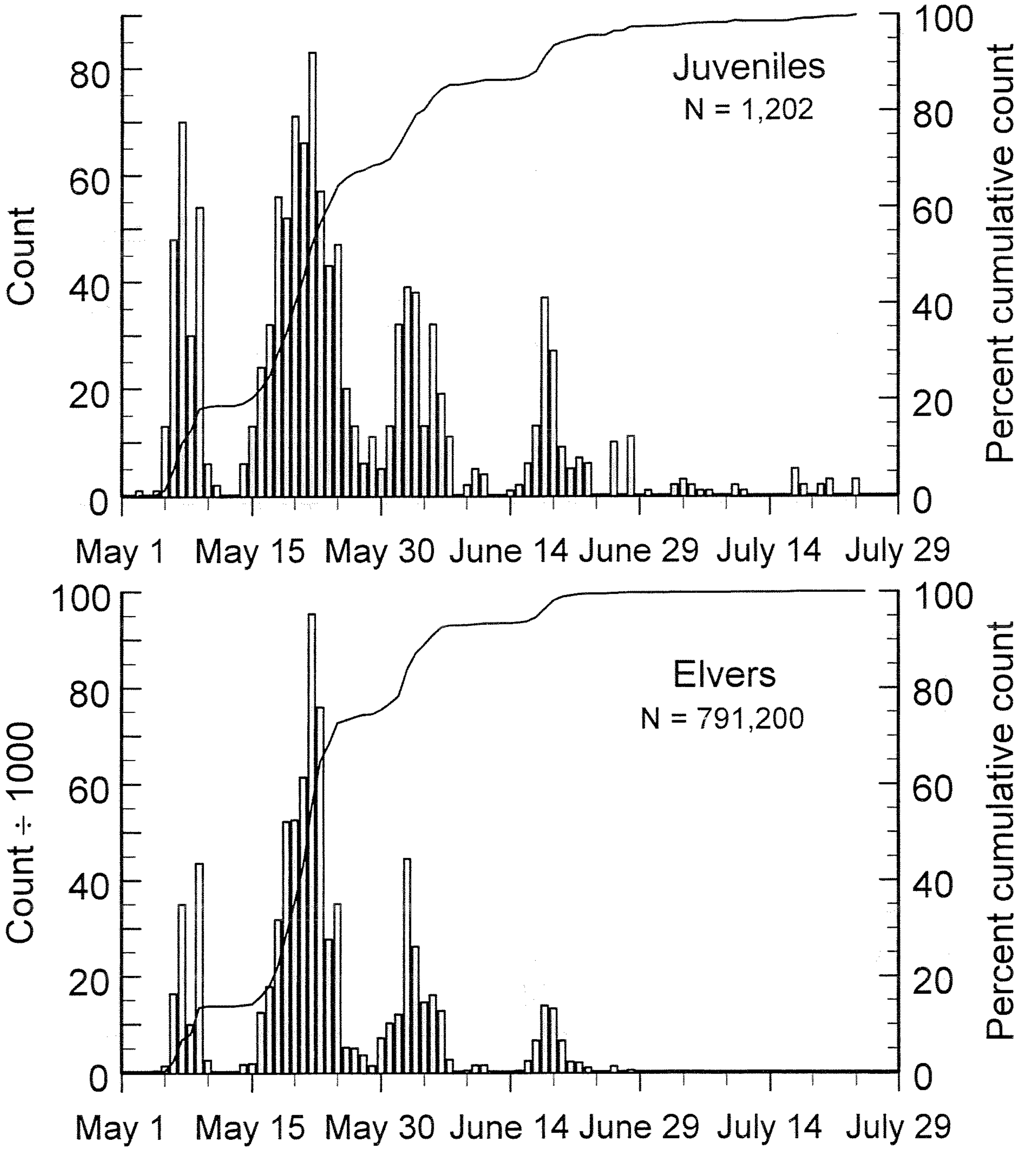

Figure 5. Daily (bars) and cumulative percent counts (line) of juvenile and elver American eels from the East River, Chester, Nova Scotia, 2000.

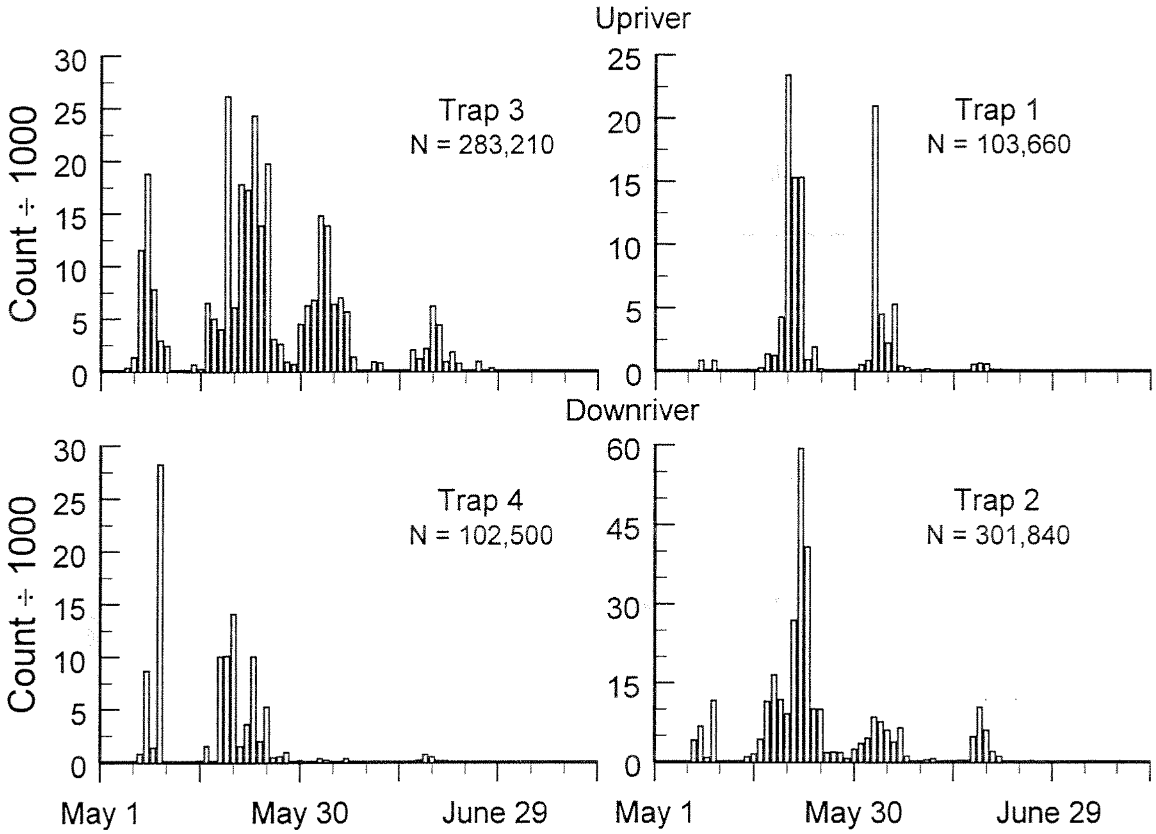

Figure 6. Daily counts of American eel elvers, by trap, from the mouth of the East River, Chester, Nova Scotia, 2000. Traps 1 and 2 were sited on the true right bank, traps 3 and 4 on the left bank. Traps 1 and 3 were located 4-5 m upstream of traps 2 and 4.

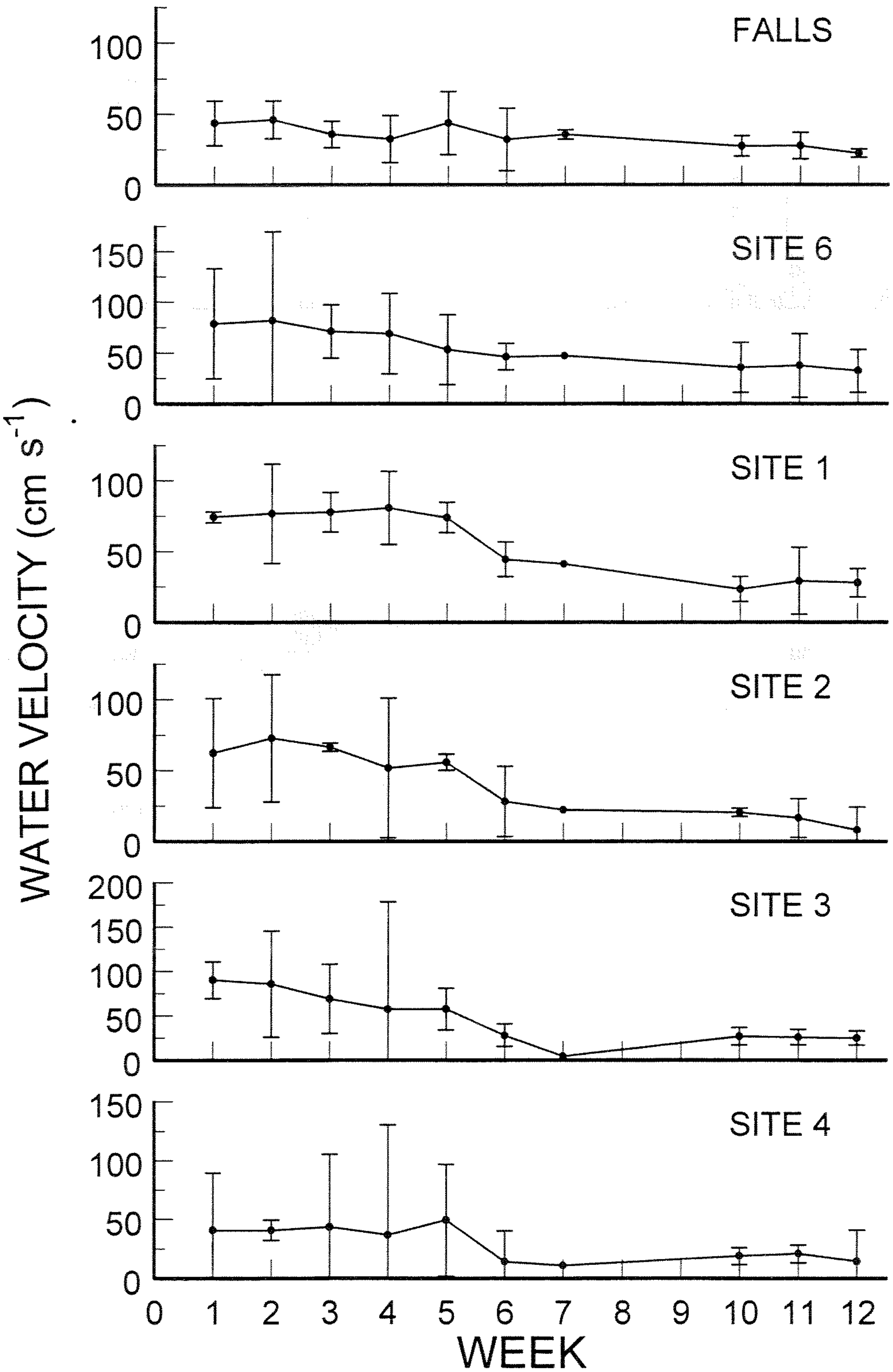

Figure 7. Mean (± 95% CI) water velocity, by site and week, for the East River, Chester, Nova Scotia, 2000. Weeks (in brackets): April 30-May 6 (1), May 7-13 (2), May 14-20 (3), May 21-27 (4), May 28-June 3 (5), June 4-10 (6), June 11-17 (7), June 18-24 (8), June 25-July 1 (9), July 2-8 (10), July 9-15 (11), July 16-22 (12).

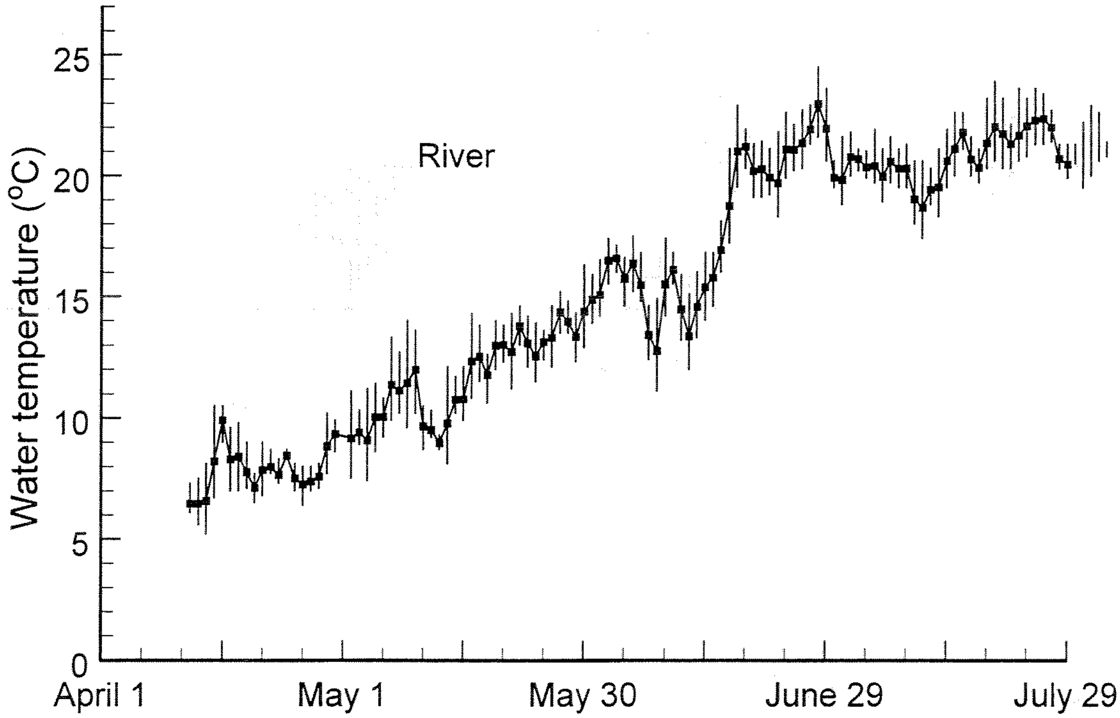

Figure 8. Daily mean and range of water temperatures from the East River, Chester, Nova Scotia, 2000.

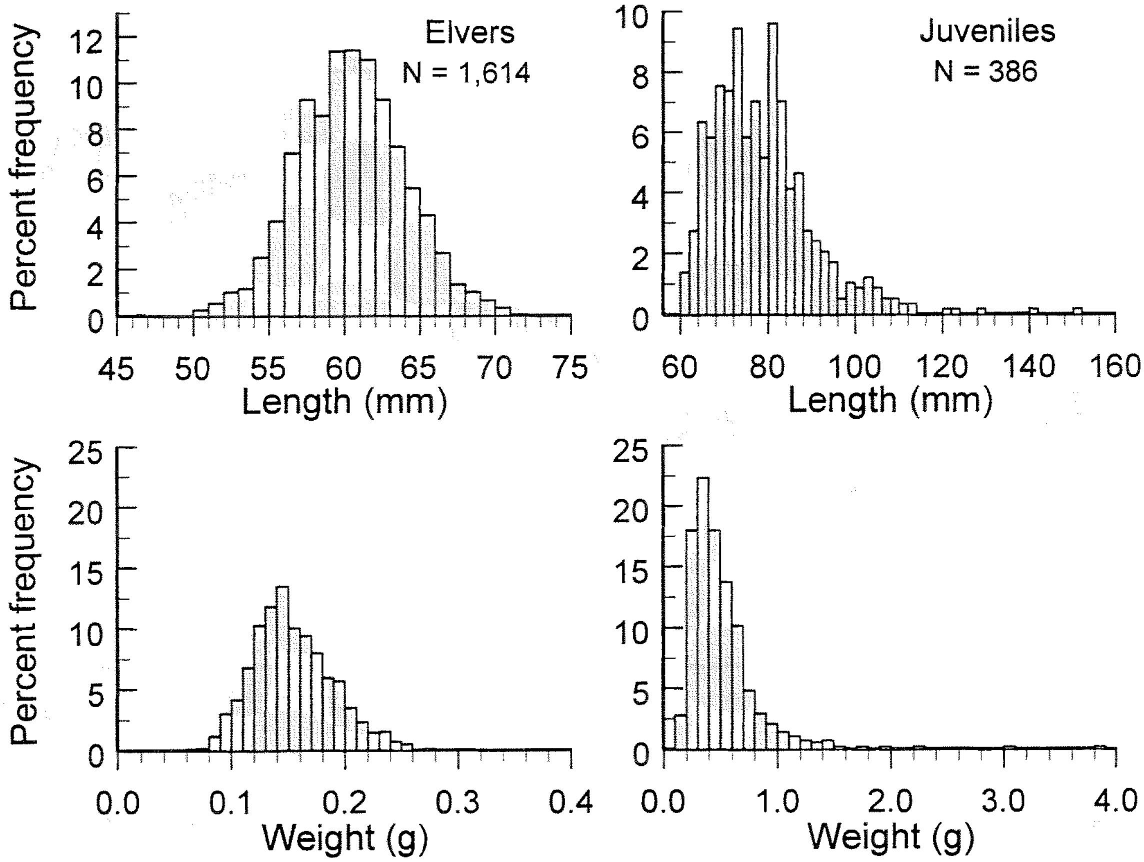

Figure 9. Total lengths and weights of elvers and juvenile American eels from the mouth of the East River, Chester, Nova Scotia, 2000. One juvenile eel of 161.4 mm length and 5.32 g weight is not shown in the figure.

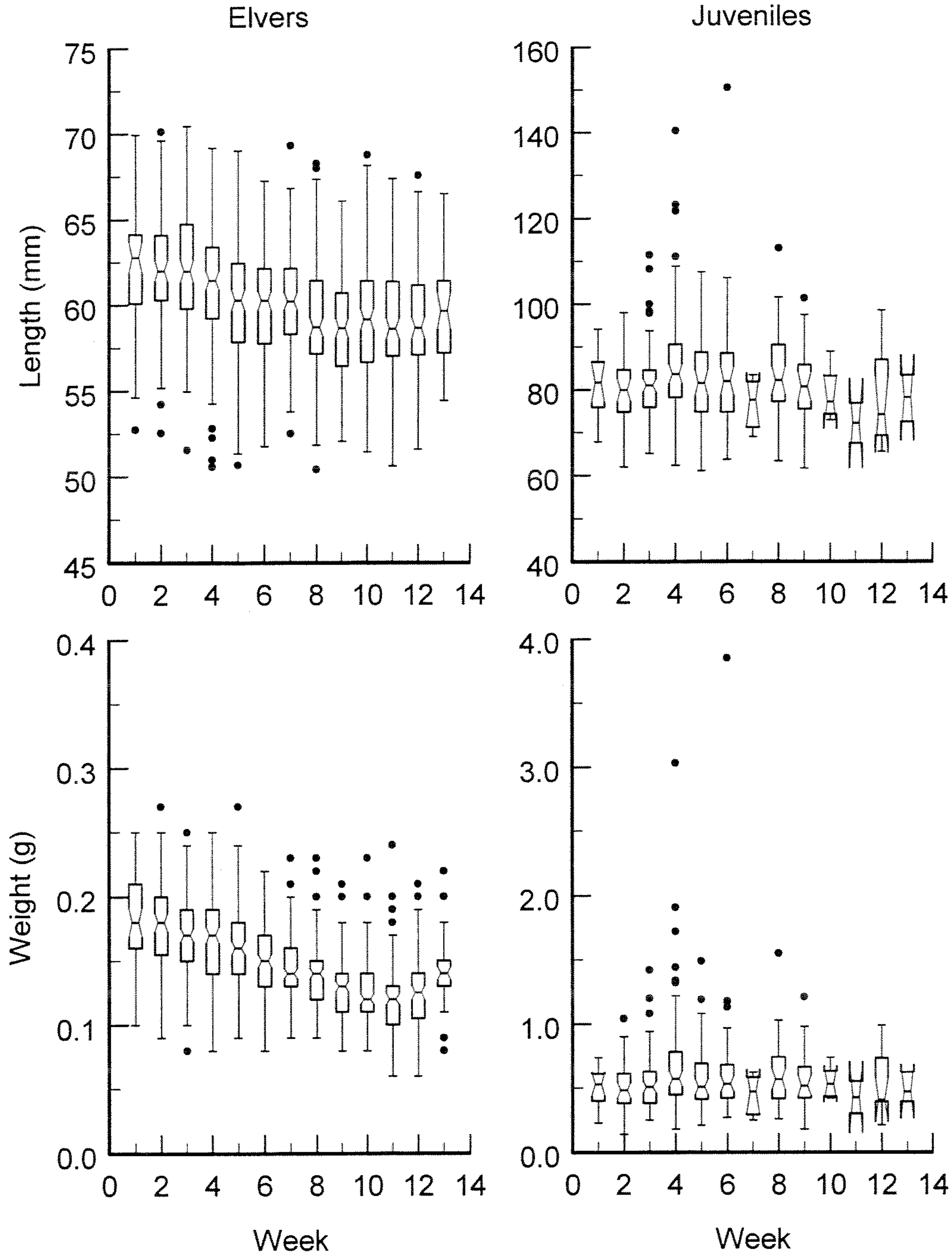

Figure 10. Median and sample distribution of lengths and weights of elvers and juvenile American eels, by week, from mouth of the East River, Chester, Nova Scotia, 2000. The center of the horizontal line marks the median of the sample distribution, the limits of the notches approximate a 95% confidence 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: (1: April 30-May 6) 50, 63, (2: May 7-13) 100, 135, (3: May 14-20) 150, 222, (4: May 21-27) 150, 230, (5: May 28-June 3) 150, 204, (6: June 4-10) 150, 193, (7: June 11-17) 150, 157, (8: June 18-24) 150, 190, (9: June 25-July 1) 150, 172, (10: July 2-July 8) 150, 127, (11: July 9-15) 125, 127, (12: July 16-22) 100, 110, (13: July 23-29) 39, 42.

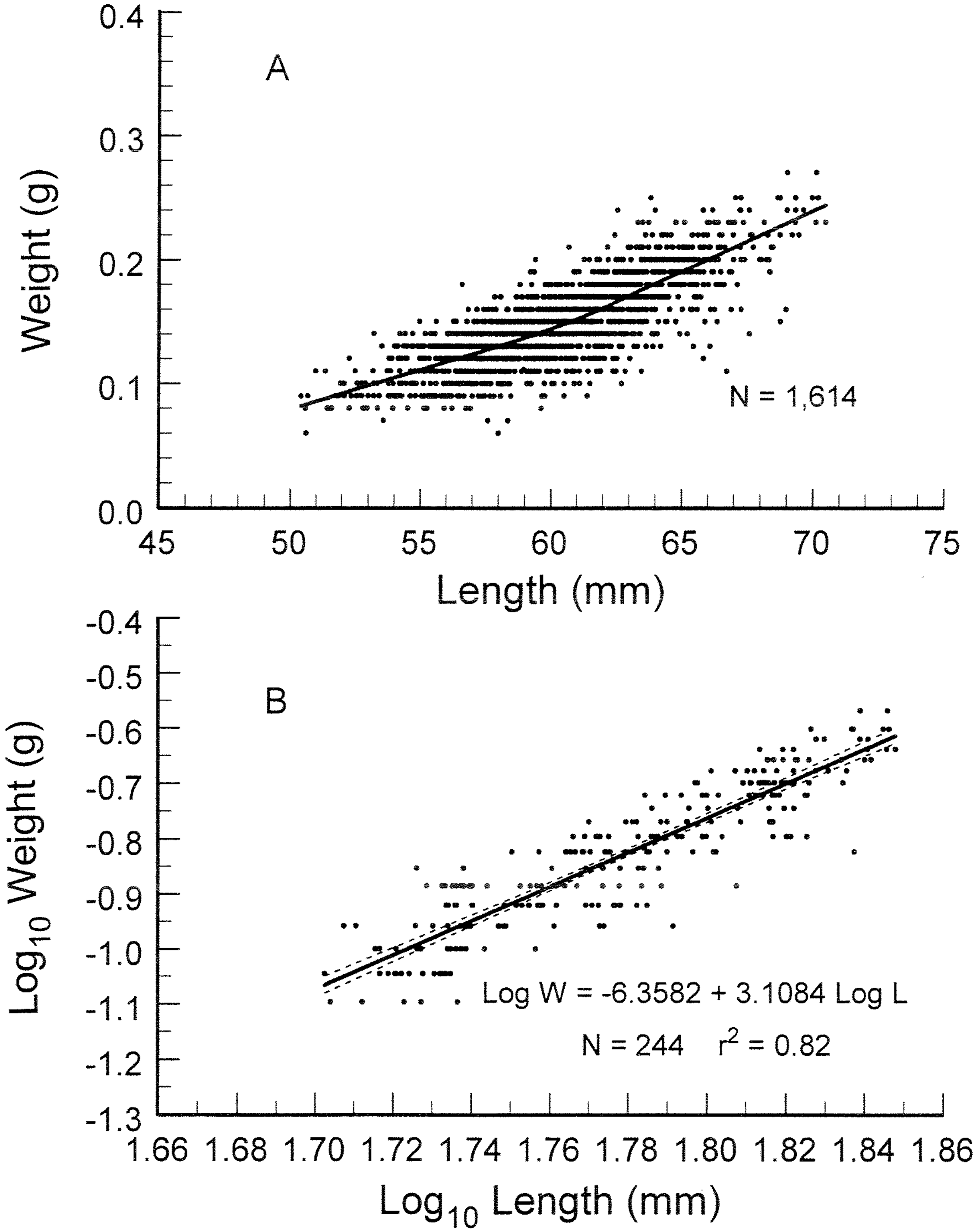

Figure 11. Weight-length distribution of (A) the observed data and (B) logarithmically transformed values of a randomly selected subset of the data, with linear regression equation and 95% confidence limits (wide dash) for American eel elvers from the East River, Chester, Nova Scotia, 2000.

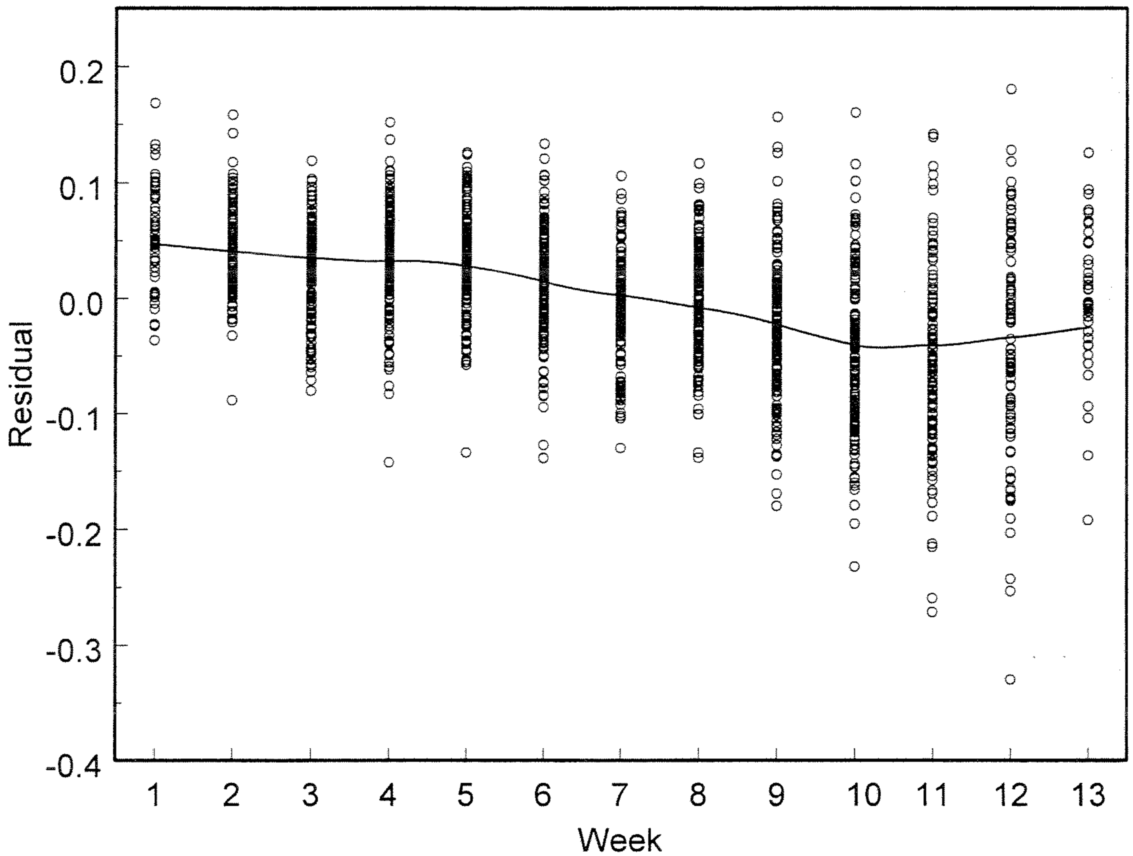

Figure 12. Seasonal trend in the index of condition of American eel elvers from the East River, Chester, Nova Scotia, 2000. The index of individual elver condition was estimated as the residual from the weight-length regression of the logarithmically (base 10) transformed data. The line is loess smoothed (tension = 0.4).

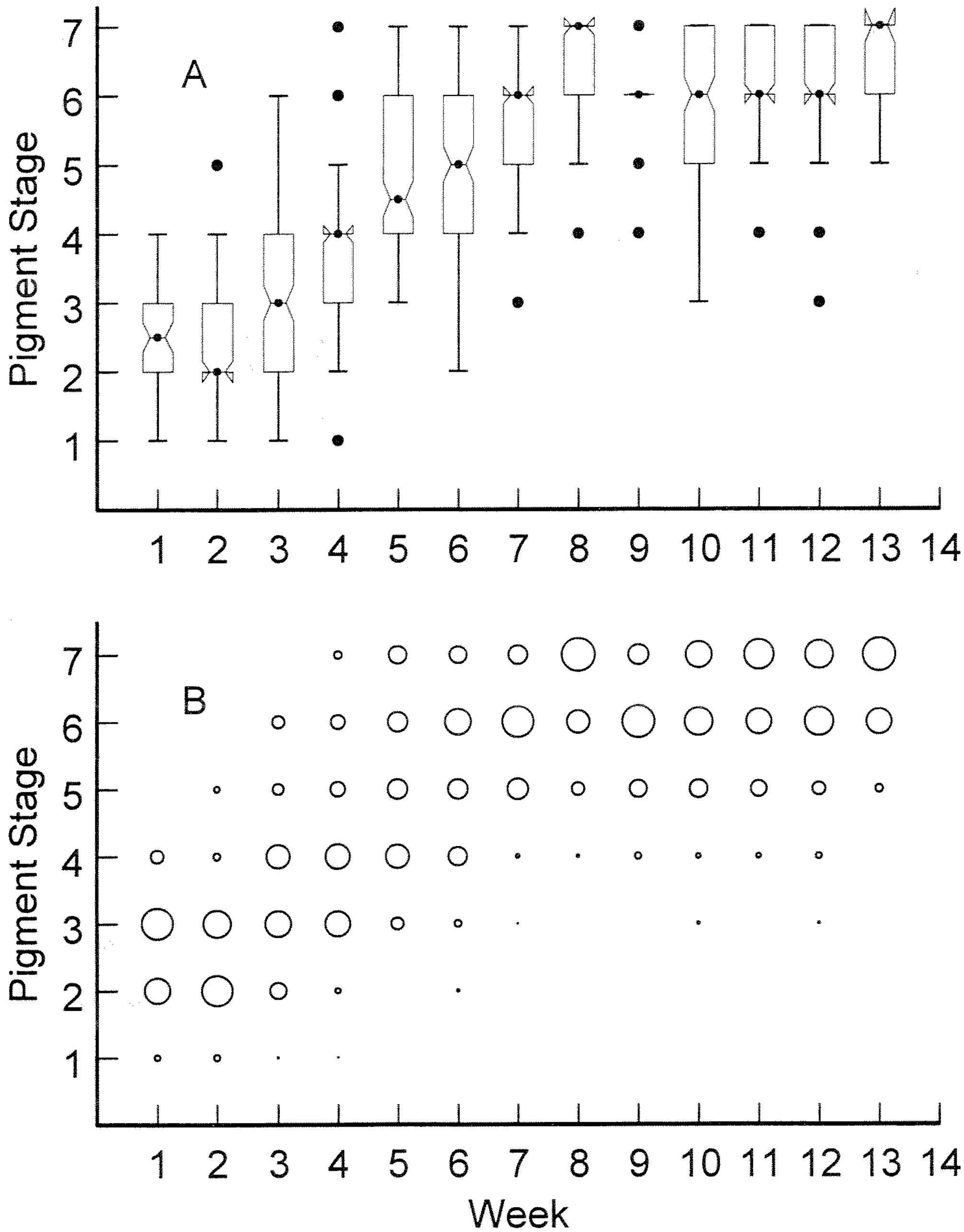

Figure 13. Median and sample distribution (A) and sample density distribution (B), by week, of the pigmentation stage of American eel elvers from the East River, Chester, Nova Scotia, 2000. Sample sizes, by week (in parentheses) were: (1: April 30-May 6) 50, (2: May 7-13) 100, (3: May 14-20) 150, (4: May 21-27) 150, (5: May 28-June 3) 150, (6: June 4-10) 150, (7: June 11-17) 150, (8: June 18-24) 150, (9: June 25-July 1) 150, (10: July 2-July 8) 150, (11: July 9-15) 25, (12: July 16-22) 100, (13: July 23-29) 39.

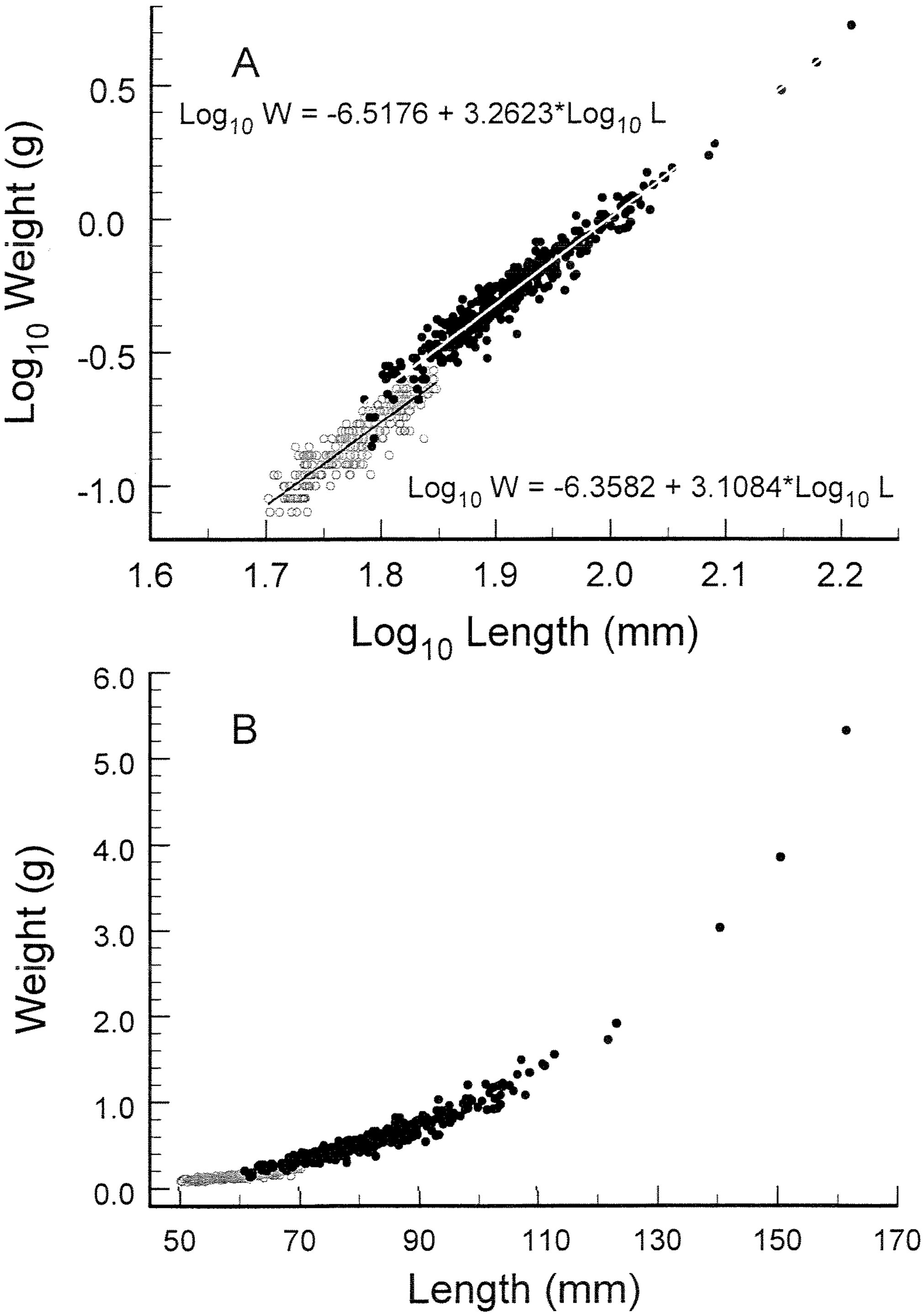

Figure 14. Weight-length relations, base 10 logarithm transformed (A) and untransformed (B), for American eel elvers (light coloured, open dots) and juveniles (dark, solid dots) from the East River, Chester, Nova Scotia, 2000.

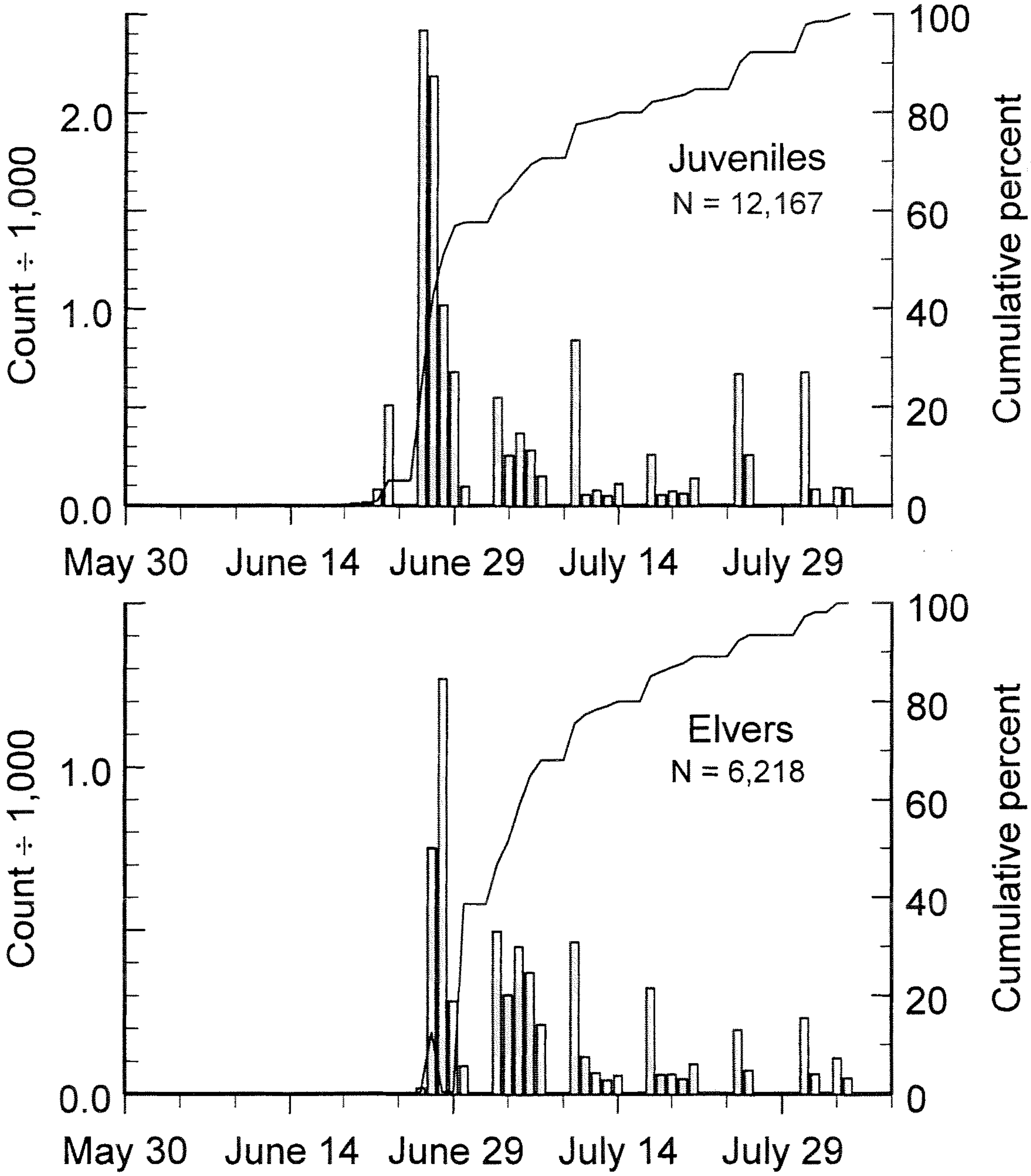

Figure 15. Daily (bars) and cumulative percent counts (line) of elver (B) and juvenile (A) American eels from the upriver, Highway 103 culvert area of the East River, Chester, Nova Scotia, 2000.

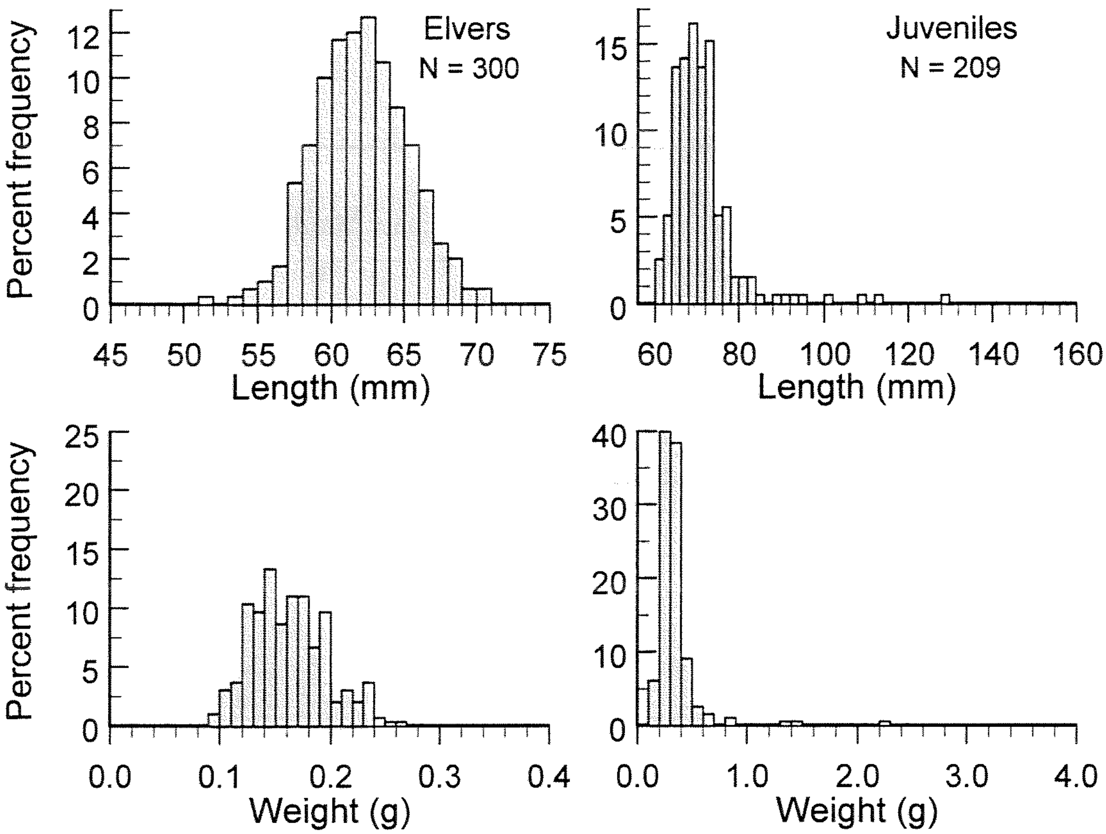

Figure 16. Total lengths and weights of elvers and juvenile American eels from the upriver, Highway 103 culvert trap site, East River, Chester, Nova Scotia, 2000. Eleven juvenile eels are not included in the figure, ranging in length and weight from 160 mm and 4.40 g to 240 mm and 13.63 g although a maximum weight of 15.41 g was recorded for an eel of 225 mm.

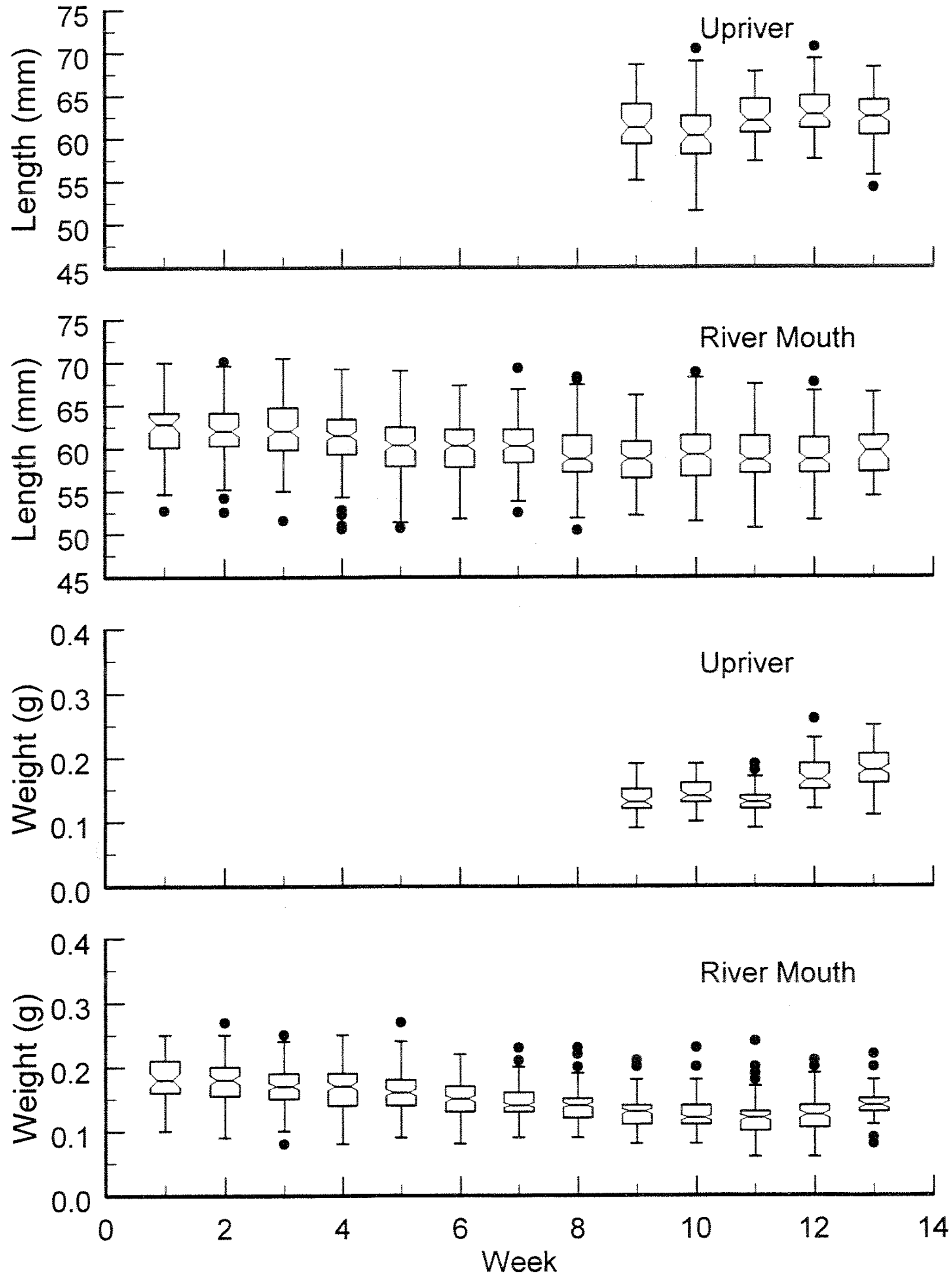

Figure 17. Median and sample distribution of lengths and weights of American eel elvers, by week, from the East River, Chester, Nova Scotia, 2000. The center of the horizontal line marks the median of the sample distribution, the limits of the notches approximate a 95% confidence interval about the median, 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) were, at the river mouth: (1: April 30-May 6) 50, (2: May 7-13) 100, (3: May 14-20) 150, (4: May 21-27) 150, (5: May 28-June 3) 150, (6: June 4-10) 150, (7: June 11-17) 150, (8: June 18-24) 150, (9: June 25-July 1) 150, (10: July 2-July 8) 150, (11: July 9-15) 125, (12: July 16-22) 100, (13: July 23-29) 39; total *N* = 1,614. Upriver: (9) 50, (10) 50, (11) 50, (12) 50, (14: July 30-August 5) 100; total *N* = 300.