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Size, and exploitation rate by dip net fishery, of the run of American eel, *Anguilla rostrata* (LeSueur), elvers in the East River, Nova Scotia

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Abstract

Between 1996 and 1998, the annual run of American eel (*Anguilla rostrata*) elvers to the East River, Chester, varied by a factor of 3.3, from about 432 000 to 1 420 000 elvers, while catch by the commercial dip net fishery varied by a factor of 2.1, from 224 200 to 463 300 elvers. Annual total exploitation by the dip net fishery ranged from 30.8 to 51.8%. Over 97% of the elvers entered the river in 4-6 waves over the duration of the run. Exploitation rates estimated from seasonal total catch and effort data were 18-28% lower than values estimated from daily data while catchability coefficient (q) values were 96-98% lower. The seasonal mean of the daily exploitation rates overestimated the seasonal exploitation rate while use of the total catch and run size during the fishery period underestimated the seasonal catchability coefficient (q). The DeLury and Leslie catch depletion methods produced estimates of elver abundance within a wave that were 32-81% lower, exploitation rates that were 24-73% higher, and catchability coefficient (q) values similar to, or higher than, those estimated by daily fishery and trap catch data. The short duration of, and natural decline in, elver abundance in the latter portion of a wave of elvers may substantially bias catch depletion methods and make them unsuitable for estimating population size, exploitation rate, and catchability coefficient (q) values for waves of elvers migrating upstream. Annual exploitation rates by a dip net fishery of 30-50% of the elver run may have little effect on the abundance of yellow and silver eels where the natural mortality rate of elvers is high.

Keywords: American eel elvers, run size, dip net fishery, exploitation rate, catchability.

Introduction

The international demand for elvers of several *Anguilla* species for aquaculture has, since 1989, resulted in development of a fishery for elvers of the American eel (*Anguilla rostrata*) in the Bay of Fundy regions of New Brunswick and Nova Scotia and along the Atlantic coast of Nova Scotia (Jessop 1997a, 1998a,b). Elver catches in this area, hereafter termed the Scotia-Fundy area, increased from 26 to 713 kg between 1989 and 1993 and ranged from 1574 to 4122 kg between 1994 and 1998 (Jessop 1998a, unpubl. data). The elvers are marketed primarily in Taiwan and China although a developing regional eel culture industry uses small quantities. The elver fishery uses a variety of gears, of which the most common are dip nets, fyke nets and pots. Minimally, about 52-66%, and maximally, about 75-87%, of the annual elver catch in the Scotia-Fundy area is made by dip net, depending on whether only the dip net is used or the dip net is used in conjunction with another gear type.

Concerns about the status of regional stocks and the continental population of American eels has intensified the scrutiny of commercial fisheries that harvest all continental life stages, including elver, yellow (juvenile), and silver (sexually maturing, prespawning) (Peterson 1997, ASMFC 1999). An understanding of fishery exploitation rates is essential to effective fishery management. Few estimates of exploitation rate exist for any eel life stage (ASMFC 1999, EPRI 1999). The single reported estimate of exploitation rate for an elver fishery ranged from 44 to 75% for a set net and hand trawling fishery in the mouth and nearby coastal waters of a Taiwan river (Tzeng 1984).

Catchability (q), defined as the fishing mortality per unit of fishing effort, is a key parameter in fish stock assessment (Arreguín-Sánchez 1996). Catchability reflects the efficiency of fishing and is involved in estimates of both resource abundance and fishing mortality, which are the basic estimates of fish stock assessment. Many yield models assume that catchability is constant when it really is highly variable. Consequently, the assumptions that catchability is independent of biomass and that catch per unit of fishing effort is independent of population density may not be met. Estimates of elver catchability for any type of gear seem unavailable.

This study estimates the seasonal and daily exploitation rates and the catchability coefficient (q) by the dip net fishery of the run of American eel elvers at the mouth of the East River, Chester, and estimates the size of the run entering the river during the years 1996-1998.

Study area

The East River, Chester, drains a watershed area of 134 km^2 into Mahone Bay and is located slightly south of midway along the Atlantic coast of Nova Scotia at 45°35'16"N, 64°10'02"W (Figure 1). The mouth of the river drops about 1.1 m over a distance of

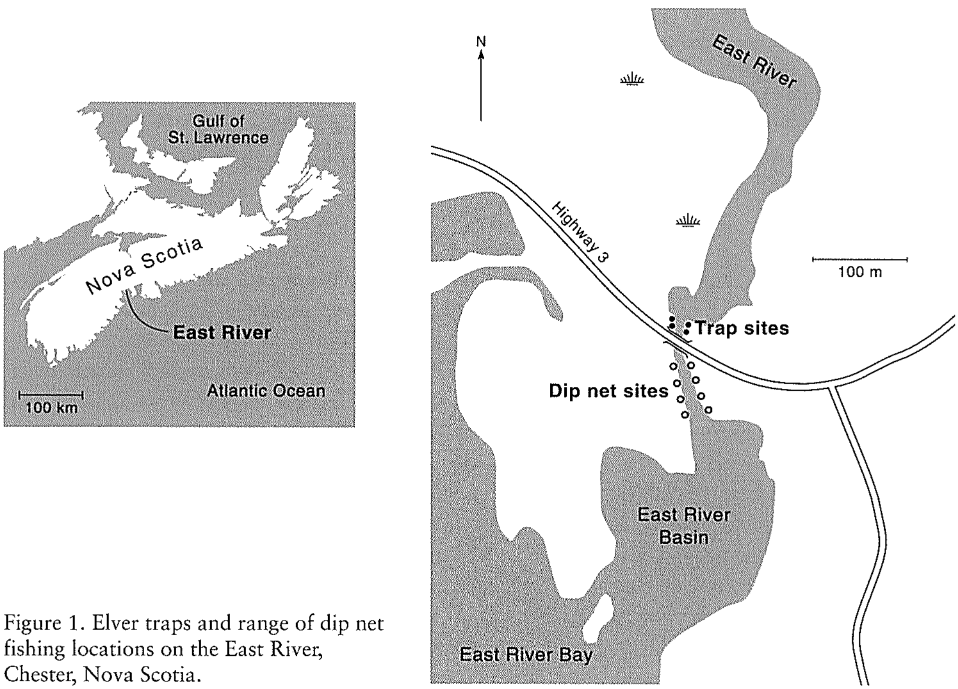

Figure 1. Elver traps and range of dip net fishing locations on the East River, Chester, Nova Scotia.

10.6 m (slope 0.11) between the small falls at the outlet of the river and the high-tide mark. Most of the vertical drop (about 0.6 m) occurs at the fall line or within 2-3 m of it. A pond-like flatwater occurs immediately upstream of the falls and extends about 770 m upstream. The river lies within the highly acidified Southern Upland zone of Nova Scotia and has water of pH 4.7-5.0 which is colored brown due to organic acids from bog areas in the drainage (Watt 1987). American eels are the dominant species in the river, by a factor of at least four (Watt *et al.* 1997). Additional site description is given in Jessop (2000).

Glass eels (unpigmented elvers) appear in river estuaries along the southwest shore of Nova Scotia at least as early as mid-March (W. Carey, commercial fisherman, pers. comm.). The commercial fishery for elvers in this area typically begins in mid- or late April, peaks in May or early June, and ends by late June (Jessop 1998a,b). Elvers, by definition, are juvenile, age-0 eels of varying degrees of pigmentation following continental arrival (the state of pigmentation increases as the run progresses). In Atlantic coastal Nova Scotia and New Brunswick, elvers are typically less than 70 mm in length and 0.3 g in weight during entrance into fresh water (Jessop 1998b).

Materials and methods

Between 1996 and 1998, four Irish-style elver traps (O'Leary 1971), two on each side of the river, were operated at the mouth of the East River throughout the elver run (typically early May to mid-July) with the objective of enumerating all elvers migrating upstream. Each elver trap consisted of an entrance trap, lined with geo-textile matting (Enkamat®) to enhance elver movement, through which flowed attraction water (Jessop 2000). Elvers reaching the head of the entrance trap were flushed into a holding box. Concrete ramps lined with Enkamat® extended from the trap mouths to below the water surface. The traps were situated downstream of the small falls at the river mouth and at, or upstream of, the head of tide. The vertical drop at the fall line and associated high water velocities were expected to prevent upstream movement of elvers except when water velocities declined with seasonally reducing discharge and where elvers could find convenient, near-shore paths bypassing the water velocity barriers. The possibility that elvers could bypass the main stream obstructions was investigated by periodic dusk-to-midnight surveys of the shoreline area so as to detect elver upstream movement and then prevent it by blocking all pathways by physical barriers. Damp, low spots and narrow channels along the shore where low water velocities occurred were filled in, thereby forcing elvers back into the main stream.

Elver catches were estimated daily for each trap, with individual elvers counted when numbers were less than about 150 elvers; otherwise, elver numbers were estimated volumetrically in approximately 50-100 milliliter aliquots, by calibrated graduated cylinder. Each year, the graduated cylinder was calibrated twice (early and mid run to account for the decrease in elver length and weight during the run (Haro & Krueger 1988, Jessop 1998b) using nine calibration counts at 50 milliliters (and 75 and 100 milliliters in some years) on each occasion. The slope of the regression of count on volume was such that the count at 100 milliliters was essentially twice that at 50 milliliters. The mean calibrated elver count at a volume of 50 milliliters was used, for each calibration period, as the calibration constant (c) to estimate daily elver catch for each trap as: Catch = $c((\Sigma V_i)/50)$ where V_i = volume of the ith measurement. This is equivalent to $\hat{Y} = N\bar{y}$ where $\hat{Y}$ is the total daily trap catch for a given calibration period, N is the number of 50-milliliter aliquots and $\bar{y}$ is the mean calibration count at 50 milliliters. The annual count of elvers caught at the river mouth was the sum of the daily trap counts (volumetric estimates plus individual elver counts) during the run (Jessop 1997b, 1998c, 1999). Confidence intervals (CI) for the annual trap count were based on the variances of the cylinder calibrations at 50 milliliters applied to the trap count for the period during which the calibration applied. The variance of the estimated trap catch for each calibration period was estimated as $S^2_{\hat{Y}_i} = (N^2S^2)/n$ where N is the number of 50 milliliter aliquots, S^2 is the variance of the calibration counts at 50 milliliters, and n is the number of calibration counts for the ith ($i = 1,2$) calibration period (Cochran 1977). The trap catches for the two calibration periods were summed to obtain the total trap catch for the run. The standard error of the estimated total trap catch $S_T = \sqrt{S^2_{\hat{Y}_1} + S^2_{\hat{Y}_2}}$ was used to estimate 95% confidence intervals in the standard manner, i.e., total trap catch $\pm t_{0.05,\mathrm{df}}\,S_T$. Catches during each calibration period were assumed to be independent.

A commercial dip net fishery was conducted at night throughout the elver run by two fishers at the river mouth in a zone about 40-100 m downstream of the elver traps. Although small quantities of elvers were evident in the upper estuary prior to the start of the fishery, the fishery was conducted between 17 April and 20 June in 1996, between 11 May and 12 June in 1997, and between 17 April and 13 June in 1998. No fishery occurred during periods when environmental conditions were judged unlikely to favor elver capture, e.g., falling tides between late afternoon and midnight, or the sharply decreasing water temperature, increasing discharge, and disturbed surface water conditions associated with heavy rainfall.

The dip nets used were 76 cm in diameter, 20 cm in depth, and of 1-mm^2 mesh. During 1998, a fine-meshed wing net was often (7 of 12 nights when catch occurred) placed upstream of the dipping site to concentrate elvers in the dipping zone. Nightly catch (to 0.01 kg drained weight) and fishing effort (to 0.25 h for each unit of fishing gear used) was recorded in a fishery logbook. Catch per unit of fishing effort (CPUE) was calculated as the nightly weight of elvers caught per hour fished. Comparisons among years of mean nightly catch, effort, and CPUE were made by random permutation analysis of variance (ANOVA) (Edgington 1995). Confidence intervals for the mean annual catch, effort, and CPUE (and median CPUE) were calculated by randomization (bootstrap accelerated bias-corrected percentile (BCa) method) with 5000 replications because of the small sample sizes and highly skewed distribution of daily catch and CPUE values (Efron & Tibshirani 1993, Edgington 1995). All other types of randomization tests in this study used 5000 replications.

The estimated catch of elvers for the ith week was $\hat{N}_i = C_i/\bar{w}_i$ where C_i is the weekly catch weight and $\bar{w}_i$ is the mean weight of the weekly sample of elvers (n = 150 for most weeks) sampled in the trap catch (Jessop 1997b, 1998c, 1999). The total fishery catch is the sum over all weeks. Daily fishery catch (kg) was converted to number of elvers, for each week, by first subtracting 25% of the daily catch weight to adjust for adhered water. Commercial fishers estimate the 'dry' quantity of elvers for marketing by subtracting 25% of the wet weight obtained after standard weighing procedures as representing adhered water (W. Carey, elver fisher, pers. comm.). The 'dry weight' correction factor was independently estimated at 21.4 ± 3.6% (95% CI) in 1997 by three replicate weighings of about 1 kg of elvers using the procedures followed by elver fishers and then followed by additional drying to estimate the amount of retained water. The 21.4% estimate is probably biased low (the first estimate was 24.5%, the final estimate was 18.3%) because of a gain in weight by elvers when repeatedly immersed in water while progressively being stripped of their protective coating of slime by the soaking and drying process. Thus, the 25% water retention correction factor used by commercial fishers was judged appropriate.

An approximate variance for the catch in the ith week was obtained by using the 'delta method'. This involved approximating N_i as a linear function of the mean weight of the ith week, $\bar{w}_i$, about the true mean weight and then taking the variance of the linear approximation, giving $\mathrm{Var}(\hat{N}_i) \approx \hat{N}_i^2 (S_{\bar{w}_i}^2 / \bar{w}_i^2)$. Note that $S_{\bar{w}_i}$ is the sample standard error of the mean weight. The variance of the total catch estimate, $\hat{N}$, is the sum of the weekly variances. This assumes independence among the weekly samples. The standard error of the estimated total catch is the square root of this approximate variance. A symmetric 95% CI was obtained in the standard manner.

Exploitation rate (ER) or dip net fishing efficiency was calculated as ER (%) = fishery catch/(fishery catch + trap catch) ×100, under the assumption that the total run = fishery catch + trap catch. An approximate variance for ER was estimated by the 'delta method' where $\mathrm{Var}(\hat{ER}) \approx 1/(\hat{N}+\hat{Y})^2 [(1-\hat{ER})^2 S_{\hat{N}}^2 + \hat{ER}^2 S_{\hat{Y}}^2]$. It was assumed that $\hat{N}$ and $\hat{Y}$ are statistically independent. An approximate standard error for ER was obtained by taking the square root of the variance. Confidence intervals (95%) for the exploitation rate were estimated in the standard manner.

Daily exploitation rates by the dip net fishery for each year were estimated by overlapping the catch modes for each wave of elvers caught by the fishery and by the traps and applying the ER (%) formula. Typically, a lag of 1-3 days occurred between modal catches for each wave of elvers entering the river (Figure 2). Confidence intervals for the mean daily exploitation rate (%) for each year were calculated by the BCa method with 5000 replications (B) because of the non-normal (hypergeometric) distribution of percentages and small sample sizes (Cochran 1977, Efron & Tibshirani 1993).

Daily catchability coefficients (q) for each wave during 1996, 1997, and 1998 were estimated as the fraction of the estimated daily elver stock (the sum of the elver dip net catch on day t and the elver trap catch on day $t + l$, where l is the lag between modal elver catches in each gear) caught by one hour of dip net fishing. Confidence intervals (95%) for the mean daily catchability coefficient (q) for each wave, except 1998 when only two daily values were available for each wave, and the annual pooled daily values were estimated by the bootstrap BCa method. The mean catchability coefficient (q) for each wave of elvers in 1996 (four waves) and in 1997 (three waves) was compared among waves and among all three years by random permutation 1-way ANOVA (Edgington 1995). Homogeneity of variances was examined by F_{max} test (Sokal & Rohlf 1981). Sample variances were homogeneous ($p > 0.05$) unless otherwise noted.

The original size (population) of each wave or shoal of elvers was estimated by the DeLury and Leslie catch depletion methods (Ricker 1975, Tzeng 1984). The DeLury method regresses daily CPUE (logarithmically transformed) on cumulative fishing effort for each wave of elvers, as indicated in Figure 2, while the Leslie method regresses daily CPUE on cumulative catch. Cumulative fishing effort and catch were adjusted by adding half the effort or catch expended in the ith interval ($0.5\ f_i$) to reduce the bias towards underestimating the population size N (Ricker 1975). The percent

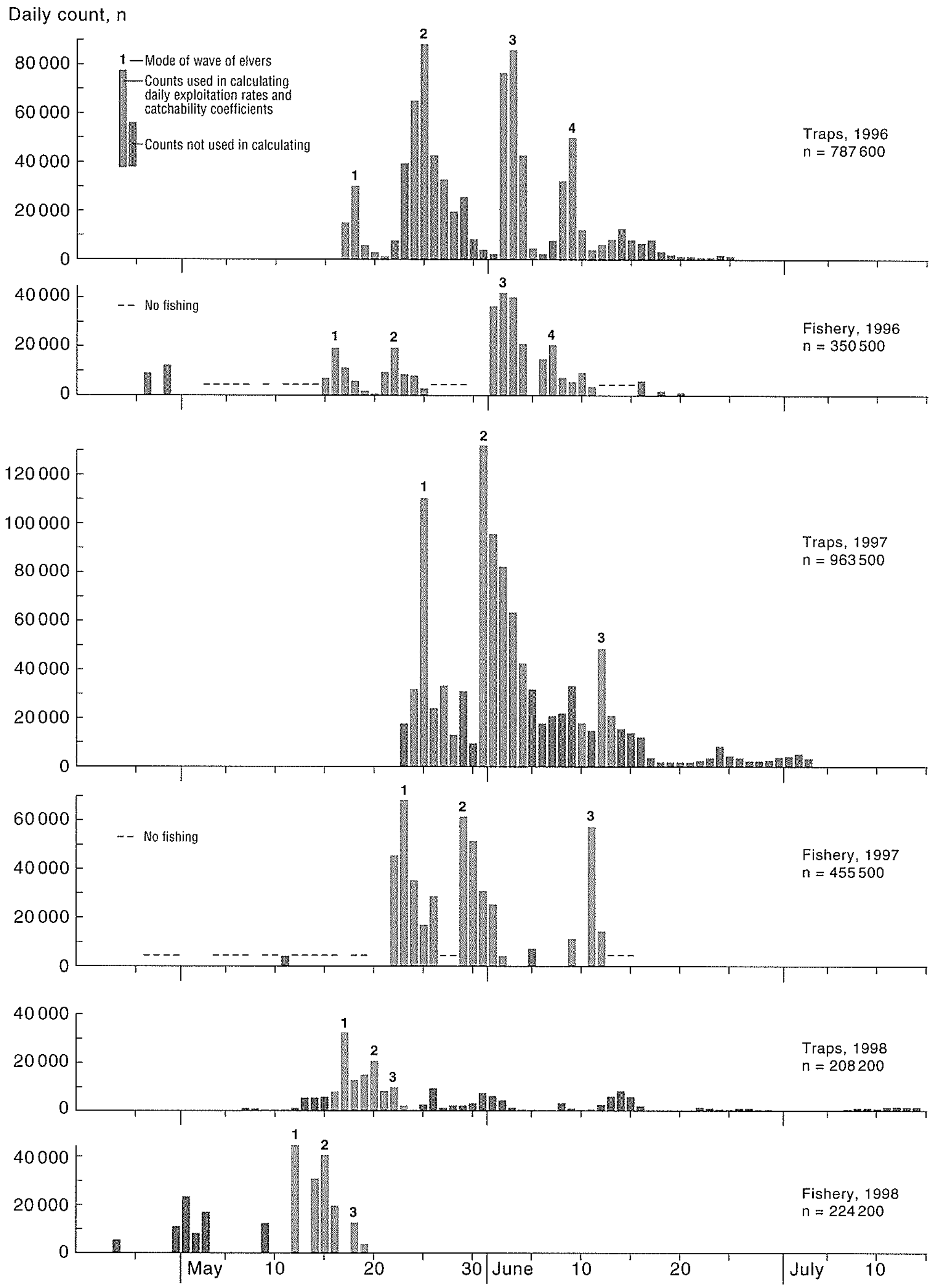

Figure 2. Daily counts, by year, of American eel elvers caught by the commercial dip net fishery and by elver trap at the mouth of the East River, Chester, Nova Scotia. The blue shading indicates those daily counts used in calculating daily exploitation rates and catchability coefficients (q).

deviation of N from the observed count data was estimated as: deviation (%) = (100 (count – N)/count). Confidence intervals (95%) for the DeLury and Leslie population estimates were estimated as in Ricker (1975, p. 150). Catchability (q) and 95% CI for the catch depletion models was estimated from the regression slopes and their standard errors. When the population size of an elver wave was based on the DeLury and Leslie population estimates of elver abundance, confidence intervals (95%) for the exploitation rate were estimated in a manner similar to that used previously to estimate confidence intervals for the exploitation rate based on fishery and trap catches.

Results

The mean daily catch, effort, and CPUE of the elver fishery in the East River, Chester, all varied significantly (all ANOVA $p < 0.004$) among years, e.g., catch and CPUE were less in 1998 than in 1997 and fishing effort was higher in 1996 than in 1997 or 1998 (Table 1). Among years, mean daily catch ranged from 1.08 to 4.10 kg, effort ranged from 3.60 to 7.64 h, and CPUE ranged from 0.177 to 0.567 $kg \cdot h^{-1}$. The annual distributions of daily catch and CPUE values were positively skewed (all $p < 0.025$) but fishing effort was usually not skewed ($p > 0.10$; significance accepted at $p < 0.10$). Skewed distributions of catch and CPUE resulted mainly from the high percentage of nights with zero catch (1996: 24%, 1997: 50%, 1998: 77%).

Elver runs to the East River varied from about 434 000 elvers in 1998 to 1.48 million elvers in 1997 while dip net fishery annual total exploitation varied from 30.8% in 1996 to 51.8% in 1998 (Table 2). Although the data are limited, the exploitation rate

Table 1. Annual means with 95% confidence interval (CI) and skewness (g_1) of the distribution of daily values and its significance (p, one-tail test) for the daily catch, fishing effort, and catch per unit effort (CPUE) from the dip net fishery for American eel elvers in the East River, Chester, Nova Scotia.

		Year		
		1996	1997	1998
	Sample size	33	30	53
Catch (kg)	Mean	2.616	4.101	1.078
	95% CI	1.794 - 3.905	2.318 - 6.547	0.535 - 1.936
	Skewness (g_1)	1.467	1.313	2.641
	p	<0.001	<0.005	<0.001
Effort (h)	Mean	7.636	4.300	3.604
	95% CI	6.280 - 9.030	3.067 - 5.650	2.807 - 4.594
	Skewness (g_1)	0.350	0.565	0.770
	p	>0.10	>0.05	>0.10
CPUE ($kg \cdot h^{-1}$)	Mean	0.336	0.567	0.177
	95% CI	0.230 - 0.480	0.348 - 0.856	0.090 - 0.310
	Median	0.238	0.125	0.000*
	95% CI	0.111 - 0.333	0.000 - 0.683	
	Skewness (g_1)	1.415	0.975	2.165
	p	<0.001	<0.025	<0.001

*More than 50% of the CPUE values were zero.

may decrease with increasing run size. Over 97% of the elvers entered the river in 4-6 waves during the run (Figure 2). The catchability coefficient (q) for the annual fishing period ranged from 0.0012 to 0.0030. Under the assumption that natural mortality occurs after elver fishing ends (unrealistic, but necessary where no estimate of elver natu-

Table 2. Annual elver catch by dip net fishery and Irish-type elver traps, total run size, and fishery total exploitation rate with 95% confidence intervals (CI), and catchability (q) of the American eel elvers entering the East River, Chester, Nova Scotia.

Year	Catch (± 95% CI) Fishery	Traps	Total run	Exploitation, %	Catch-ability*
1996	350 500 (±7 300)	787 600 (±23 100)	1 138 100 (±24 200)	30.8 (±0.8)	0.0012
1997	455 500 (±9 700)	963 500 (±23 100)	1 419 000 (±52 100)	32.1 (±1.3)	0.0025
1998	224 200 (±5 200)	208 200 (± 6 900)	432 400 (± 8 200)	51.8 (±1.0)	0.0030

*Catchability was based on the run size to the end of the fishery.

Table 3. Daily fishing exploitation rates (ER), by date and year, for the dip net fishery for American eel elvers in the East River, Chester, Nova Scotia. Dates are based on trap catches; • indicates mode of each wave of elvers.

	1996 Date	1996 *ER*, %	1997 Date	1997 *ER*, %	1998 Date	1998 *ER*, %
	17 May	33.1	24 May	58.8	17 May •	58.1
	18 May •	39.5	25 May •	38.1	19 May	67.2
	19 May	69.8	26 May	60.1	20 May •	66.5
	20 May	68.3	27 May	33.5	21 May	70.6
	21 May	86.3	28 May	69.7	22 May •	56.0
	24 May	12.5	31 May •	31.1	23 May	59.0
	25 May •	17.8	1 June	35.0		
	26 May	16.4	2 June	7.1		
	27 May	19.8	3 June	28.3		
	28 May	12.3	4 June	7.9		
	2 June	31.6	10 June	38.6		
	3 June •	32.6	12 June •	53.5		
	4 June	48.1	13 June	40.6		
	5 June	83.9				
	8 June	31.4				
	9 June •	28.7				
	10 June	38.4				
	11 June	60.1				
	12 June	58.8				
	13 June	32.0				
Mean		41.07		40.18		62.9
Median		32.85		38.10		62.7
Range		12.3-86.3		7.9-69.7		56.0-70.6
95% CI		32.32-51.73		31.36-48.55		58.72-67.30
Fishery coverage (%)*		80		87		50
Catch coverage (%)**		91		98		67

*Percentage of the total number of days fished. **Percentage of the total fishery catch.

ral mortality rate is available for this period), the instantaneous rate of fishing mortality (F) (Ricker 1975) was estimated as 0.350 in 1996, 0.375 in 1997, and 0.728 in 1998. Run size and mean daily CPUE over the fishing season were slightly positively correlated ($n = 3$, $r = 0.96$, $p_{(one\text{-}tail\ test)} < 0.10$). No significant decrease occurred in the seasonal exploitation rate (arcsine $\sqrt{p}$ transformed) with increasing run size ($n = 3$, $r = -0.76$, $p_{(one\text{-}tail\ test)} > 0.25$). The seasonal catchability coefficient (q) also did not decline with increasing run size ($r = -0.44$, $p_{(one\text{-}tail\ test)} > 0.50$). Instead, catchability (q) may vary non-linearly with run size.

Daily exploitation rates by the dip net fishery averaged 41.07% in 1996, 40.18% in 1997, and 62.90% in 1998 (Table 3). Annual (fishing season) exploitation rates based on total fishery catch and run sizes (Table 2) were 18-28% lower than the seasonal means of the daily exploitation rates (Table 3). Daily exploitation rates were calculated for 50-87% of the run period and 67-98% of the fishery catch, depending upon the year.

In 1996, the mean daily catchability coefficients (q) for individual waves of elvers ranged from 0.016 to 0.066 but did not differ significantly ($F = 2.79$, $df = 3,16$, $p = 0.11$) among the four waves of elvers observed (Table 4). In 1997, wave mean daily catchability coefficients ranging from 0.034 to 0.085 did not differ significantly ($F = 5.51$, $df = 2,10$, $p = 0.06$). However, heterogeneous variances ($F_{max} = 101.0$, $p < 0.05$) for the wave mean daily catchability coefficients in 1996 and small and unequal sample sizes

Table 4. Mean, range, and 95% confidence interval (CI) for the daily catchability coefficient (q), by wave and year, for American eel elvers in the East River, Chester, Nova Scotia.

Year	Wave	Sample size	Mean	Range	95% CI
1996	1	5	0.066	0.020-0.116	0.040-0.092
	2	5	0.016	0.012-0.021	0.013-0.019
	3	4	0.062	0.032-0.012	0.032-0.106
	4	6	0.065	0.027-0.128	0.045-0.101
	Total	20	0.052	0.012-0.128	0.039-0.071
1997	1	5	0.071	0.038-0.116	0.047-0.095
	2	5	0.034	0.026-0.047	0.028-0.042
	3	3	0.085	0.064-0.101	0.064-0.097
	Total	13	0.060	0.026-0.116	0.046-0.078
1998	1	2	0.074	0.073-0.075	
	2	2	0.070	0.070-0.071	
	3	2	0.230	0.244-0.236	
	Total	6	0.125	0.026-0.236	0.072-0.202

($n = 3\text{-}6$) in both years may bias and reduce the power of the ANOVA comparison of means. The mean daily catchability coefficient for wave 2 of 1996 may actually differ from those of the other waves in 1996 and the mean daily catchability coefficient of wave 2 in 1997 may differ from the means of waves 1 and 3. Note that comparison of the degree of overlap of the 95% CI for the wave mean daily catchability coefficients for determination of significant difference is inappropriate for multiple comparison purposes due to the absence of a family-wise error rate and of a common (pooled) variance, amongst other reasons. Pooling of the daily catchability coefficients of individual

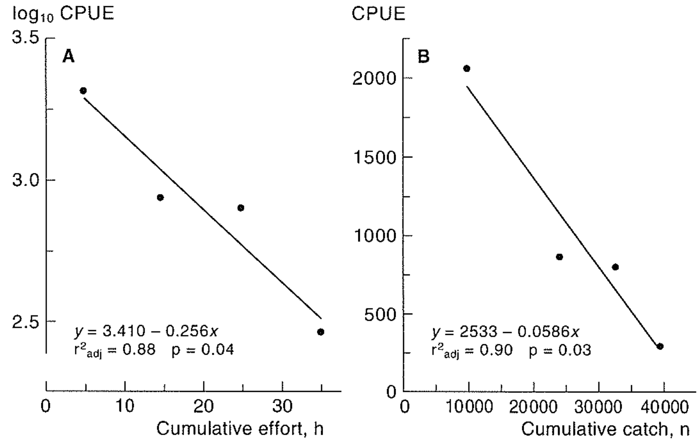

Figure 3. Regressions of CPUE (elvers$\cdot$h^{-1}, log$_{10}$-transformed) on cumulative effort (h) for the DeLury method (A) and of CPUE (elvers$\cdot$h^{-1}) on cumulative catch (elvers) for the Leslie method (B). The catch and effort data is from wave 2 of the 1996 elver run (see Figure 2). The adjusted r^2 corrects r^2 to reflect the goodness of fit of the model relative to the population rather than the sample.

waves within a year gave annual means that differed among years ($F = 6.36$, df = 2,36, $p = 0.008$), with 1998 having a higher mean catchability coefficient than 1996 or 1997 due to the high coefficient values observed in wave 3 of 1998. Seasonal catchability coefficients based on total fishery catch, effort, and run size (Table 2) were 96-98% smaller than those based on the seasonal means of the daily catchability coefficients (Table 4).

Estimates of elver population size, exploitation rate, and catchability (q) within a wave or shoal of elvers were highly biased and less precise (relatively wider confidence intervals) when based on the DeLury and Leslie methods, which were similar in result, when compared with estimates based on known fishery and trap catch data (Table 5).

Table 5. Annual population size, exploitation rate, and catchability (q), with 95% confidence intervals (CI), based on trap count and fishery data and the DeLury and Leslie methods, and the deviation between count and regression methods, for selected waves of elvers entering the East River, Chester, Nova Scotia. Regressions on which the DeLury and Leslie methods were based ranged in significance (p) from 0.03 to 0.21, r^2_{adj} ranged from 0.44 to 0.90, and n was either 4 or 5. The adjusted r^2 corrects r^2 to reflect the goodness of fit of the model relative to the population rather than the sample.

Year:	1996		1997
Wave:	1	2	2
Population size (95% CI)			
Count	77 900 (73 800-81 900)	229 200 (217 500-241 000)	602 100 (576 200-628 100)
DeLury	52 700 (37 000-91 300)	43 600 (36 500-54 100)	225 500 (175 400-315 500)
Deviation (%)	−32.4	−80.9	−62.5
Leslie		43 200 (29 500-60 500)	235 460 (136 200-387 800)
Deviation (%)		−81.0	−60.8
Exploitation rate (%) (95% CI)			
Count	50.7 (48.0-53.2)	17.2 (16.0-18.5)	29.0 (27.5-30.5)
DeLury*	74.8 (39.8-100.0)	90.6 (73.0-100.0)	77.5 (51.7-100.0)
Difference	24.1	73.3	48.5
Catchability (q) (95% CI)			
Count	0.066 (0.040-0.092)	0.016 (0.013-0.019)	0.034 (0.028-0.042)
DeLury*	0.056 (0.000-0.114)	0.059 (0.036-0.082)	0.039 (0.015-0.063)

* Exploitation rates and catchability values for the Leslie method were similar to those for the Delury method and have not been shown.

Of the seven waves in 1996 and 1997 having at least three data points available to estimate the regressions of the DeLury and Leslie methods, only elver wave 2 of 1996 produced regressions statistically significant at $p < 0.05$ for either method (Figure 3). The short duration of a wave of elvers results in a small sample size for regression purposes and may produce non-significant results at $p < 0.05$ even when a substantial (44-51%) part of the variance is accounted for. Consequently, statistical significance requirements were relaxed (significance accepted at $p \leq 0.21$) and regressions were estimated by the DeLury method for waves 1 and 2 in 1996 and wave 2 in 1997 and by the Leslie method for wave 2 in 1996 and in 1997.

DeLury and Leslie estimates of elver wave population size underestimated the count estimates, with an average deviation of −64.6% (Table 5) for the DeLury population estimates. Exploitation rates for individual waves of elvers were consequently higher when based on the lower DeLury and Leslie elver abundance estimates for a given wave. Thus, for wave 1 in 1996, the exploitation rate by the DeLury method was 74.8% while by the count data it was 50.7%, for a difference of 24.1%. Confidence intervals for the population and exploitation rate estimates based on the DeLury and Leslie methods were quite wide, tending to increase as statistical significance of the underlying regression declined.

Catchability (q) values estimated by the DeLury method and by count data were similar for those waves with regressions not significant at $p < 0.05$ but the confidence intervals were much wider for the values estimated by the DeLury method (Table 5). For wave 2 of 1996, where the regression was significant ($p = 0.04$), the DeLury estimate of q (0.059) was higher, possibly significantly higher based on the non-overlap of 95% confidence intervals, than the value (0.016) estimated from the count data.

Discussion

Trends in fishery catch over time, whether intraseasonally or interannually, may reflect changes in either abundance or fishing mortality, or both. Estimates of the size of the elver run to the East River, Chester, varied by a factor of 3.4, from 434 000 to 1.48 million elvers, while fishery catch varied by a factor of 2.1, from 224 200 to 463 300 elvers, during the years 1996-1998. The assumption that the total run = fishery catch + trap catch is believed accurate. The logbooks of daily catch and effort were from fishers that had an interest in and provided partial funding for the study. The experimental trap catch was based on observation of the total run period and the traps were sited at a natural barrier that is impassable under most conditions due to high water velocity (Jessop 2000). Under lower water conditions, active measures were taken to prevent or minimize the possibility of elver bypass.

Annual (fishing season) total exploitation by the dip net fishery varied from 30.8 to 51.8%. Tzeng (1984) estimated exploitation rates ranging from 44.1 to 75.4% by a hand trawl fishery in a Taiwanese river. The correlation between increasing annual mean CPUE and increasing run size, although based on a minimum sample size (3) and of marginal significance ($p < 0.10$), is consistent with fishery dynamics theory and with the assumptions necessary to estimate population size by catch-effort methods (Ricker 1975, Hilborn & Walters 1992). Although the decrease in annual exploitation rate and the associated catchability coefficient (q) with increasing stock size was not significant, probably due to the minimal sample size and high variability in these parameter values, such a decrease is also consistent with fishery theory. However, the indication of a non-linear relation between catchability (q) and run size is of interest. Environmental conditions, e.g., tidal height, river discharge, and water temperature may influence elver behavior and run timing (Martin 1995) and thus affect catchability. The high exploitation rate and catchability (q) value at a low run size may reflect the shoaling behavior of elvers (Tesch 1977, Arreguín-Sánchez 1996) and the concentrating effect in the upper estuary of selective tidal stream transport on elver density (Tesch 1977, McCleave & Kleckner 1982). The usefulness of catch and effort data for monitoring elver abundance should be evaluated by determining how the catchability coefficient (q) varies with changing environmental conditions and with stock abundance (Arreguín-Sánchez 1996).

Mean daily catchability coefficients (q) differed among waves of elvers annually entering the East River but no systematic trend was observed either within a wave or among waves over a run. Systematic trends in catchability coefficient (q) over time tend to bias estimates of population size, with increases in catchability overestimating population size (Hilborn & Walters 1992).

The lower value and lower variability of exploitation rate and catchability (q) coefficient values estimated from seasonal total values rather than from daily values is due to several factors. The use of total seasonal values of catch and effort to calculate seasonal exploitation rate and catchability (q) coefficients effectively applies unequal daily weights by using the seasonal sum of the observed daily catch and effort values. Averaging daily exploitation rates and catchability coefficients over the fishing season gives equal weight to the daily catch and abundance values. However, the fishery may occur over a shorter period than does the total run and, during the fishing period, not all days are fished due to adverse environmental conditions (inappropriate tidal phase, heavy rain, high river discharge), and on some fishing days there is no catch. Varying environmental conditions greatly affect the variability of daily catch and fishing effort values. Methodological problems also occur, such as the inability to estimate population size, exploitation rate, or catchability for portions of the elver run when no distinctive wave pattern occurs.

The consequence of different parameter estimates, depending upon the method used, is that care must be taken to choose the appropriate parameter values to use for any given purpose. The use of daily CPUE values is preferred to seasonally pooling catch and effort to obtain a seasonal mean CPUE value (Ricker 1975). A similar approach is advisable for estimating the seasonal mean catchability coefficient (q) but exploitation rate is probably most useful when estimated on a total seasonal basis if an accurate estimate of the population size is available. Use of the seasonal mean of the daily exploitation rates tends to overestimate the seasonal exploitation rate while use of the seasonal total catch and run size tends to underestimate the seasonal catchability coefficient (q). Daily exploitation rates and catchability coefficients (q) are usually difficult to estimate and the assumption of equal daily weights is often made (Ricker 1975) despite the biases inherent in that assumption (Arreguín-Sánchez 1996).

Catch-effort methods may be inappropriate to estimate the abundance of elvers in any of the several waves comprising an annual elver run to many Nova Scotian streams for several reasons. The DeLury and Leslie methods did not accurately estimate elver abundance within a wave during the run in any year. Catch rates must be proportional to fish abundance if CPUE is to be used as an index of abundance or density. For catch rate to be proportional to abundance, fishing effort must be randomly or systematically distributed with respect to the fish and not concentrated, as fishermen often do, in high abundance areas (Hilborn & Walters 1992). The relation between fish abundance and CPUE is also biased when fish migrate through a local fishing zone because the ratio of CPUE to abundance depends on the duration of fishing and CPUE varies through the run (Sampson 1991). The assumed linear relation between both exploitation rate and catchability (q) and fishing effort may be valid when fishing effort is relatively modest but may become asymptotically nonlinear (additional gear catches increasingly smaller fractions of the population) when fishing effort is greatly increased and gear competition occurs. The bias associated with gear competition may be minor for this dip net elver fishery. Although fishing activity occurred through most of the elver run, it was particularly intensive during a wave of elvers, and two dip net fishers actively fishing were sufficient to catch a high proportion of a small run. More importantly, the seasonal pattern of the dip net fishery catch and CPUE reflects the abundance and pattern of the elver run (Jessop 1998a, this study), particularly the short run duration and dominance by several waves of elvers, each of which usually only persists for 3-5 days. Consequently, the DeLury and Leslie regressions were based on so few data values that they were usually non-significant despite accounting for a substantial degree of variance. Elver runs to North American streams in the northern portion of their range are shorter than the more protracted elver runs in Asian or Europe (Tzeng 1984, Cantrelle 1981). Variability was increased because the elver population was not closed and the probability of capture was not constant throughout the wave duration (Ricker 1975); the daily abundance of elvers within a wave varies widely as each wave of elvers migrates upstream through the fishing area. Although fishing effort may decrease daily elver abundance, as required by catch depletion methods, the depletion effect is exaggerated by the wave pattern of elver abundance during the run. The duration and pattern of passage of elvers through the fishing zone is influenced primarily by river discharge and associated water velocity, where increasing discharge delays upstream passage, and tidal phase, which governs the movement of elvers into the upper estuary (Jessop 1997b, 1998c, 1999). Inconstant daily catchability in response to varying environmental conditions may be the most significant source of bias for the Leslie and DeLury catch depletion methods (Ricker 1975). Some elvers may be unavailable ($q = 0$) to the fishing gear due to geomorphological and river discharge conditions in the fishing zone. Bias due to imprecisely measured catch and effort is believed to be negligible. Spurious inflation of the correlation between CPUE and catch or effort due to non-independence of the CPUE values and the resultant overestimation of catchability (q) and n is likely to be of little concern relative to other biases (Hilborn & Walters 1992).

The use of regressions statistically significant at $p < 0.05$ is preferred for the DeLury and Leslie methods because they provide estimates of elver population size, exploitation rate, and catchability that are possibly more accurate and may be more precise (narrower confidence intervals) than when less statistically significant regressions are used, depending upon the sample size and range of values. However, such parameter estimates may still be significantly biased, both statistically and practically. The DeLury and Leslie methods can substantially (32-81%) underestimate the population size of a wave of elvers and consequently bias estimates of exploitation rate and catchability in the opposite direction. Even if good estimates were made of elver abundance in each of the waves comprising a run, the sum of elver abundances in each wave will underestimate the total run because elver fishing does not occur on some nights when conditions are judged by fishermen as not worth fishing (e.g., poor tide phase, heavy rain) and fishermen cease fishing when catch rates decline to uneconomic levels before the elver run is truly over. The percentage of the elver run occurring after cessation of the commercial fishery ranged from 0.7% in 1996 to 6.8% in 1998.

Annual exploitation rates by a dip net fishery that range from 30-50% of the elver run may have little effect on the abundance of yellow eels and yield of silver eels in rivers such as the East River, Chester, where the natural mortality rate of elvers is high (finite $M = 0.99$) due to adverse environmental conditions such as low pH and high predation (Jessop 2000).

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