Ageing studies on three species of freshwater mussels from a metal-polluted watershed in Nova Scotia, Canada

JANICE L. METCALFE-SMITH
Rivers Research Branch, National Water Research Institute, P.O. Box 5050, 867 Lakeshore Road, Burlington, Ont., Canada L7R 4A6

AND

ROGER H. GREEN
Department of Zoology, University of Western Ontario, London, Ont., Canada N6A 5B7

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Freshwater mussels are increasingly used to monitor metal pollution in freshwater systems. Mussels are long-lived, and age is a factor that may influence metal concentrations in their tissues. Species that can be precisely aged are most suitable for biomonitoring because they can be standardized for this factor. Precise age estimates are also needed for determining the effects of contamination on population parameters such as growth rate. *Elliptio complanata*, *Anodonta implicata*, and *Alasmidonta undulata* (family Unionidae) were collected from two Nova Scotia lakes contaminated with arsenic and mercury. Mussel shells were weighed, measured, and sectioned, and two independent counts of internal growth bands were made. External rings were also counted for *A. implicata*. Age estimates based on internal bands were most precise for *E. complanata* ($r^2 = 0.71$ vs. 0.35 for *A. implicata* and 0.29 for *A. undulata*). Estimates based on external rings were more precise ($r^2 = 0.69$) than those based on internal bands for *A. implicata*, but were believed to include disturbance rings. Shell length and weight were similarly correlated with age for a given species and population, but relationships were less clear in the lake with the more variable habitat. *Elliptio complanata* were much smaller at a given age in the more contaminated lake.

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Les moules d'eau douce servent de plus en plus à l'évaluation des métaux toxiques dans les systèmes dulcicoles. Les moules vivent longtemps et leur âge est un facteur qui peut influencer les concentrations de métaux dans leurs tissus. Les espèces dont on peut déterminer l'âge avec précision sont les plus utiles, car les mesures peuvent alors être uniformisées en fonction de ce facteur. Des estimations précises de l'âge sont également nécessaires pour déterminer les effets de la contamination sur les variables démographiques telles le taux de croissance. Des *Elliptio complanata*, *Anodonta implicata* et *Alasmidonta undulata* (famille Unionidae) ont été récoltées dans deux lacs de Nouvelle-Écosse contenant de l'arsenic et du mercure. Les coquilles des moules ont été pesées, mesurées et coupées et les bandes internes de croissance ont été comptées deux fois, de façons indépendantes. Les anneaux externes ont également été comptés chez *A. implicata*. C'est chez *E. complanata* que l'estimation de l'âge par dénombrement des bandes internes est le plus exacte ($r^2 = 0{,}71$ vs. 0,35 chez *A. implicata* et 0,29 chez *A. undulata*). Dans le cas d'*A. implicata*, les estimations basées sur les anneaux externes donnent des résultats plus précis ($r^2 = 0{,}69$) que les estimations basées sur le dénombrement des bandes internes, mais ces dénombrements semblent inclure des anneaux aberrants. La longueur de la coquille et la masse sont toutes deux en corrélation avec l'âge chez une espèce et une population données, mais ces relations se sont avérées moins claires dans le lac qui offrait l'habitat le plus variable. Dans le lac le plus contaminé, la taille des *E. complanata* en fonction de l'âge était beaucoup plus petite.

[Traduit par la rédaction]

Introduction

Marine mussels have been widely used as biomonitors of metal pollution in coastal environments around the world. Freshwater mussels have been less well studied and utilized, but have been gaining steadily in popularity (e.g., Foster and Bates 1978; Adams *et al.* 1981; Hemelraad *et al.* 1986; Czarnezki 1987; Pugsley *et al.* 1988). Recently they have been recommended for routine monitoring of metals and organic contaminants in the Great Lakes (Olive and Waller 1989).

Freshwater mussels are probably the longest lived freshwater invertebrates, the life-spans of many species ranging from 10 to 20 or even 40 years (Imlay 1982). As a result, age is potentially a major source of biological variation in contaminant biomonitoring programs that use mussels. Many workers have tried to eliminate this factor by selecting specimens of a standard size (based on tissue weight or a measure of shell morphology) both from natural populations and as transplant candidates, assuming that they are standardizing for age as well. There are several problems with this approach. First, age and size are not always well correlated due to the great variability in growth rates among individuals from some populations (Hinch and Stephenson 1987; Hanson *et al.* 1988*a*). Also, populations from different areas frequently have different age–size relationships (Magnin and Stanczykowska 1971; Hinch *et al.* 1986; Hanson *et al.* 1988*b*). Furthermore, Hinch and Stephenson (1987) found that the bioaccumulation of certain metals by *Elliptio complanata* was related to size, whereas the bioaccumulation of other metals was better predicted by age. Similarly, Williamson (1979) reported opposite and independent effects of age and body weight on concentrations of cadmium in a gastropod mollusc.

Although the life-spans of invertebrates can be determined through life-history studies, only a few groups can actually be aged. Among these groups are the corals and polychaetes, but by far the most work has been done on bivalve molluscs (Rhoads and Lutz 1980). Freshwater mussels from northern climates are particularly suitable for ageing, as their growth rings are clear because of distinct periods of growth and

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TABLE 1. A comparison of contamination of Power Mill Beach and Lake Thomas with arsenic and mercury (from Metcalfe and Mudroch 1987)

	Arsenic		Mercury	
	Lake Thomas	Powder Mill Beach	Lake Thomas	Powder Mill Beach
Water (μg/L)	2.1–2.6	0.2–4.1	nd (<0.02)	nd (<0.02)
Suspended sediment	129–490	288–319	0.46–1.02	2.25–3.30
Nearshore bottom sediment	ns	890–3050	ns	5.69
Deposition-zone sediment	163	749	10.5	20.8
E. complanata	15 (26) (n = 37)	38 (117) (n = 8)	1.7 (4.4) (n = 22)[a]	2.2 (4.2) (n = 9)[a]
A. implicata	17 (21) (n = 16)	22 (42) (n = 48)	0.6 (0.7) (n = 10)	0.8 (1.4) (n = 37)
A. undulata	ns	32 (49) (n = 16)	ns	ns

NOTE: All concentrations except water are reported in micrograms per gram dry weight. Values for the three mussel species are given as the mean concentration, with maximum concentration in parentheses. nd, not detectable; ns, no sample.

[a] Mercury concentrations were higher in larger *E. complanata*, therefore specimens of the same weight range (1.0–2.0 g dry weight) from each site are compared.

latency related to seasonal temperature changes. In contrast, growth rings in marine mussels from lower latitudes are often too obscure to permit ageing (e.g., Strong and Luoma 1981).

In the present study, ageing techniques based on shell annuli were applied to populations of mussels from two Nova Scotian lakes known to be contaminated to different degrees with arsenic (As) and mercury (Hg). The purposes of the study were to determine whether three eastern Canadian species of unionids, *Elliptio complanata, Anodonta implicata*, and *Alasmidonta undulata*, could be precisely aged, to compare age estimates based on internal growth bands versus external ring counts, to determine whether age was a good predictor of shell length and shell weight, and to compare the age–size relationships of mussel populations among species and between lakes. Precise age estimates for these species are required in order to determine the influence of age on the bioaccumulation of As and Hg by mussels. This information, in turn, is needed before the degrees of contamination of mussel populations from different lakes can be directly compared. Comparisons of age–size relationships among species provide general information on growth rates and longevity, which is useful for selecting appropriate species for biomonitoring, and comparisons between lakes may indicate whether metal contamination will affect the growth rates of mussels in the Shubenacadie Lakes.

Materials and methods

Description of study area

The Shubenacadie River headwater lakes are located north of Halifax, Nova Scotia (Fig. 1). Historic gold-mining activities, which centred around the village of Waverley at the turn of the century, led to As and Hg contamination in the watershed (Trip and Skilton 1985). Recent urban and industrial expansion in the area has disturbed the mine tailings and bedrock, aggravating an existing contamination problem. Large beds of mussels occur in the nearshore zones of two of these lakes at the sites referred to as Powder Mill Beach and Lake Thomas. A comparison of As and Hg concentrations in water, suspended sediment, bottom sediment, and soft tissues of mussels from the two sites indicates that Powder Mill Beach is more contaminated than Lake Thomas (Table 1).

Collection of mussels and ageing procedure

Mussels were collected from shallow areas (<1 m depth) at the two sites in July 1985. Ten *E. complanata*, 73 *A. implicata*, and 20 *A. undulata* were collected from Powder Mill Beach, while 54 *E. complanata* and 26 *A. implicata* were obtained from Lake Thomas. *Alasmidonta undulata* was not found in Lake Thomas. The shells were air-dried and weighed to the nearest milligram. Shell length was measured to the nearest 0.5 mm using vernier calipers. For each species at each site, 10–13 specimens representing the range of size classes present were selected for ageing.

Following the method described by Hinch and Stephenson (1987), the right valve of each specimen was coated with epoxy, cut along the axis of maximum growth, mounted on a microscope slide, then further cut to produce a thin section. The internal annual growth bands were then counted independently by two "evaluators." External rings were also counted for *A. implicata* only.

Statistical analyses

The precision of the ageing procedure based on internal bands, and also on external rings for *A. implicata*, was assessed by calculating the coefficient of determination (r^2) between the independent age estimates of the two evaluators for each series of specimens. The two estimates for each specimen were then averaged, and the "best" regression models predicting shell length and shell weight as functions of age and site were determined for each species. The best model was that in which no significant predictors were omitted but no nonsignificant predictors were included. Site could not be included as a predictor for *A. undulata* because all specimens came from Powder Mill Beach.

The "modelling run" for predicting shell length or shell weight was initiated with the following model:

$$[1] \quad y = a + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4$$

where y is predicted shell length (cm) or shell weight (g)
$a, b_1, \ldots b_4$ are partial regression coefficients
x_1 is age (average of estimates made by two evaluators)
x_2 is site (Lake Thomas = 1; Powder Mill Beach = 2)
x_3 is age^2
x_4 is age × site interaction

The terms x_3 and x_4 were never significant, therefore they do not appear in any of the regression equations. To examine differences among species and between sites in more detail, regression equations predicting shell measurements from age were also calculated separately for each site.

Results

All regression statistics relating shell measurements to age estimates based on internal band counts are presented in Table 2. Regression lines representing these relationships for each site

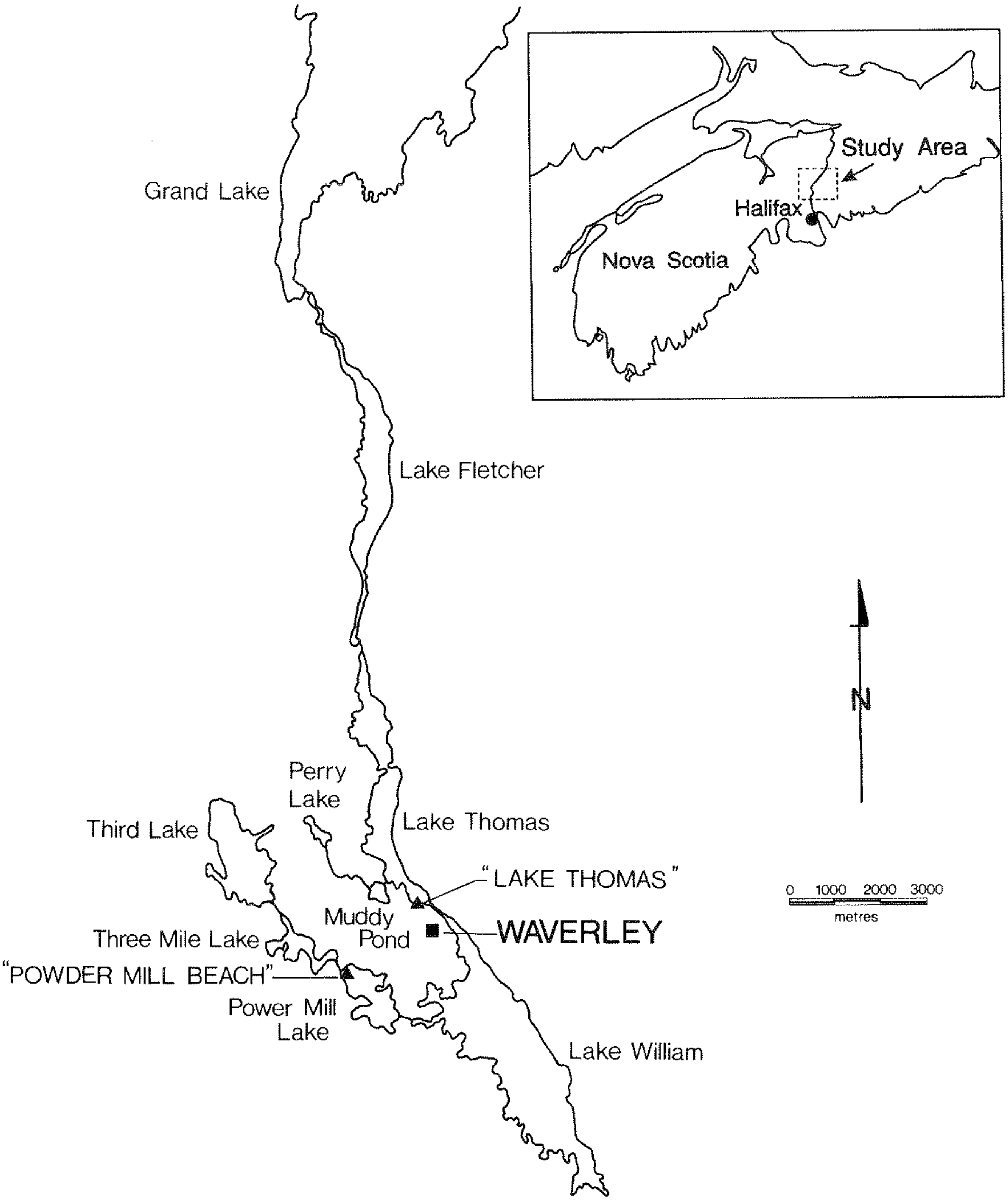

FIG. 1. Locations of study sites.

separately are illustrated in Fig. 2; regression lines using pooled data from both sites are not illustrated. The equations listed in Table 2, and others appearing in the text, are identified by consecutive reference numbers.

Elliptio complanata

Twenty-two specimens of *E. complanata* were sectioned and aged. The age estimates made by the two evaluators were significantly correlated ($r^2 = 0.71$, $t = 6.69$, df = 20, $p <$

TABLE 2. Regression statistics relating shell length (cm) and shell weight (g) to age estimates based on internal band counts

		Pooled (both sites)					Lake Thomas				Powder Mill Beach			
	y	a	b_1x_1	b_2x_2	r^2	Eq. No.	a	bx_1	r^2	Eq. No.	a	bx_1	r^2	Eq. No.
E. complanata	Length	8.00	0.30	−1.81	0.78	2	6.54	0.27	0.53	3	3.88	0.35	0.72	4
	Weight	17.41	2.51	−11.71	0.64	5	3.79	2.68	0.43	6	−3.35	2.22	0.72	7
A. implicata	Length	1.10	1.07	ns	0.49	8	2.66	0.80	0.35	9	−0.83	1.42	0.66	10
	Weight	−19.14	4.95	ns	0.44	11	−13.20	3.60	0.34	12	−27.54	6.67	0.69	13
A. undulata	Length	—	—	—	—		—	—	—		0.84	0.52	0.64	14
	Weight	—	—	—	—		—	—	—		−5.49	1.56	0.69	15

NOTE: a, b_1, b_2, partial regression coefficients; x_1, age; x_2, site; r^2, coefficient of determination; ns, not significant.

0.05 is used throughout). The slope of the line relating the two estimates was not significantly different from 1.0 ($t = 0.38$, df = 20), nor was the intercept significantly different from 0 ($t = 0.35$, df = 20), therefore both evaluators saw the same number of internal bands in a given specimen.

In the best-fitting regression equation predicting shell length from age and site for this species (eq. 2), the effects of both age and site were significant ($t_{\mathrm{age}} = 5.36$, $t_{\mathrm{site}} = 4.80$, df = 19). Mussels from Lake Thomas were larger at a given age than those from Powder Mill Beach. Individual regression lines for Lake Thomas (eq. 3) and Powder Mill Beach (eq. 4) are compared in Fig. 2*a*. The slopes of these lines did not differ significantly ($F_{[1,18]} = 0.52$), therefore the growth rates of mussels 5 years of age and older did not differ between sites. Because the intercepts were different ($F_{[1,19]} = 23.04$), it appears that mussels from Lake Thomas grew faster than those from Powder Mill Beach during their first 5 years of life.

In the best-fitting regression equation predicting shell weight from age and site for this species (eq. 5), the effects of both age and site were again significant. Individual regression lines for Lake Thomas (eq. 6) and Powder Mill Beach (eq. 7) are compared in Fig. 2*b*. The intercepts of these lines differed significantly ($F_{[1,19]} = 8.55$), but the slopes did not ($F_{[1,18]} = 0.13$).

Overall, age was a better predictor of shell length ($r^2 = 0.78$) than shell weight ($r^2 = 0.64$). When sites were tested individually, this was also true for Lake Thomas. However, age predicted both measurements equally well at Powder Mill Beach. Coefficients of determination between age and both shell measurements were higher for mussels from Powder Mill Beach.

Anodonta implicata

Twenty-five specimens of *A. implicata* were sectioned and aged. Both internal bands and external rings were counted for this species. Age estimates by the two evaluators were highly correlated for the external counts ($r^2 = 0.69$) and less well correlated for the internal counts ($r^2 = 0.35$). The latter relationship was nevertheless statistically significant ($t = 3.47$; df = 23). The intercept of the line relating the two sets of internal counts was significantly different from zero ($t = 2.51$, df = 23), with evaluator 2 counting, on average, one more band per specimen than evaluator 1.

Both evaluators saw more external rings than internal bands. The regression of external counts (y) on internal counts (x) for evaluator 1 was

[16] $y = 1.48 + 0.88x_1, \qquad r^2 = 0.50$

and for evaluator 2 was

[17] $y = 0.46 + 1.25x_1, \qquad r^2 = 0.48$

The evaluators differed in that evaluator 1 saw more external rings in younger specimens (e.g., for $x = 4$, $y = 5.0$, whereas for $x = 10$, $y = 10.2$), whereas evaluator 2 saw more external rings in older specimens (e.g., for $x = 4$, $y = 4.5$, whereas for $x = 10$, $y = 12.0$).

For comparison with the other two species, the best-fitting regression equation predicting shell length from age and site was calculated using internal band counts. In this equation (eq. 8), the effect of age was significant ($t = 4.64$, df = 23), but the effect of site was not ($t = 0.78$, df = 23). Individual regression lines for Lake Thomas (eq. 9) and Powder Mill Beach (eq. 10) are compared in Fig. 2*c*. Although these lines appear to differ, they do not differ significantly in either slope ($F_{[1,21]} = 1.77$) or elevation ($F_{[1,22]} = 0.16$). The imprecision of age estimates based on internal bands for this species resulted in a large error term that could have masked any differences in growth rates between sites. However, regression equations calculated on the basis of external ring counts, which were more precise, also indicated no differences in slope ($F_{[1,21]} = 0.73$) or elevation ($F_{[1,22]} = 2.23$) between the sites. These equations, illustrated in Fig. 3, are as follows:

[18] Lake Thomas: $y = 1.55 + 0.85x, \qquad r^2 = 0.83$

[19] Powder Mill Beach: $y = 1.05 + 0.99x, \qquad r^2 = 0.85$

In the best-fitting regression equation predicting shell weight from age and site for this species (eq. 11), only the effect of age was significant ($t = 4.20$, df = 23). Individual regression lines for Lake Thomas (eq. 12) and Powder Mill Beach (eq. 13) are compared in Fig. 2*d*.

Overall, age was a slightly better predictor of shell length ($r^2 = 0.49$) than shell weight ($r^2 = 0.44$). When sites were tested individually, there was little difference in the correlation between age and shell length or weight at both sites. As was the case for *E. complanata*, coefficients of determination between age and both shell measurements were higher for mussels from Powder Mill Beach.

Alasmidonta undulata

Twelve specimens of *A. undulata* from Powder Mill Beach were sectioned and aged. As noted earlier, none were available from Lake Thomas. Age estimates based on internal band counts by the two evaluators were not significantly correlated ($r^2 = 0.29$, $t = 2.01$, df = 10). However, for comparison

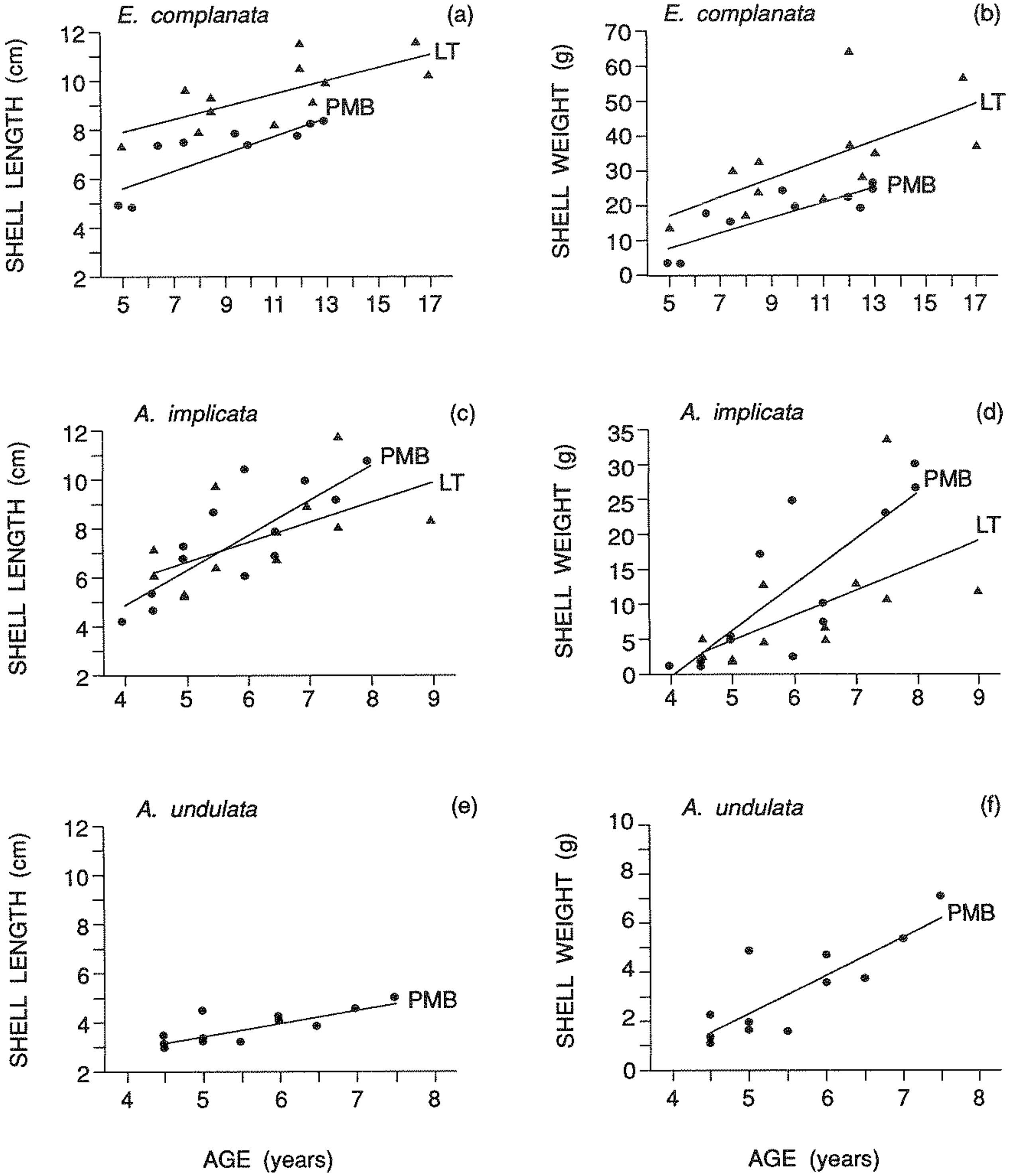

FIG.. 2. Age–length and age–weight relationships for mussels from Lake Thomas (LT, ▲) and Powder Mill Beach (PMB, ●); ages are based on internal band counts.

with the other two species average values for internal band counts were used in the prediction models.

The best-fitting regression equations predicting shell length (eq. 14) and shell weight (eq. 15) from age are shown in Figs. 2*e* and 2*f*, respectively. For this species, shell weight was slightly better predicted by age ($r^2 = 0.69$) than shell length ($r^2 = 0.64$).

Discussion

The annual nature of growth rings in the shells of temperate unionids is generally accepted, based on the mark–recapture studies of Chamberlain (1931), Negus (1966), Ghent *et al.* (1978), and Haukioja and Hakala (1978). Most workers have reported few problems distinguishing between disturbance rings, which are caused by environmental stress, and true

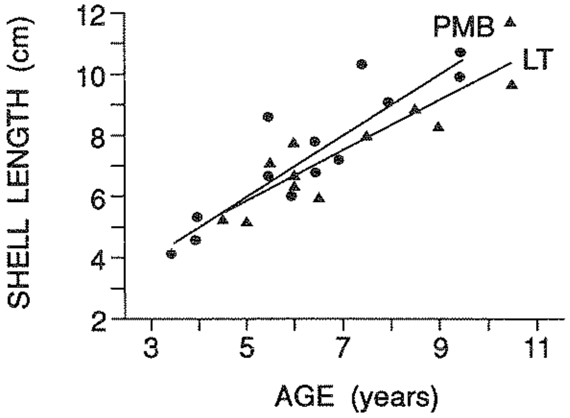

FIG. 3. Age–length relationships for *A. implicata* from Lake Thomas (LT, ▲) and Powder Mill Beach (PMB, ●); ages are based on external ring counts.

annuli. Haukioja and Hakala (1978) found such false rings to be weak and readily identified even in stunted populations of *Anodonta piscinalis* with dark shells. Imlay (1982) concluded from his literature review that the method of ageing unionids by counting the annual growth rings in their shells was reliable.

Most investigators have based their age estimates of unionids on counts of the external shell rings. Species that have been aged in this way include *A. piscinalis* (Ökland 1963; Haukioja and Hakala 1978), *Anodonta anatina* (Manly and George 1977), *Anodonta grandis* (Ghent *et al.* 1978), *Anodonta grandis simpsoniana* (Hanson *et al.* 1988*b*), *E. complanata* (Ghent *et al.* 1978; Strayer *et al.* 1981) and *Lampsilis radiata siliquoidea* and *Leptodea fragilis* (Nalepa and Gauvin 1988). However, there is evidence that counts based on external growth rings are often unreliable, particularly for specimens older than 10 years.

Ökland (1963) suspected that his age estimates based on external rings for older specimens of *A. piscinalis* could be off by 1–2 years as a result of either erosion of the oldest parts of the shell or indistinct separations between the most recent growth rings because of slower growth rates in older specimens. Haukioja and Hakala (1978) found that only individuals of this species less than 7 years of age could be accurately aged by means of external rings. Even within this age group, 12% of their specimens could not be aged. Similarly, Ghent *et al.* (1978) could not distinguish among external growth rings in most *A. grandis* older than 9 years from Lake Bernard, Ontario, because the rings were so close together. *Elliptio complanata* specimens were even more difficult to age because the umbo was so severely eroded in most specimens that the first 6 years of growth were obliterated. Clearly, information on the older age-classes may be lost or obscured when age estimates are based on external rings alone.

Techniques for preparing thin sections of shells for examination of internal growth bands have been available for over a decade (Clark 1980). Although it is more time-consuming to prepare thin sections than to count external rings on intact shells, internal ring counts are believed to be more reliable. In the present study, both evaluators saw more external rings than internal bands in *A. implicata*, suggesting that disturbance rings were being included in the external counts. In specimens such as these, which were not eroded, age may therefore be overestimated if external counts are used. Unfortunately, this finding cannot be verified, as there are no other available studies that compare counts of external and internal growth rings in unionids.

Elliptio complanata could be aged more precisely than either *A. implicata* or *A. undulata*, based on the degree of correlation between independent counts of internal growth bands. Hinch and Stephenson (1987) aged 100 specimens of *E. complanata* from two Ontario lakes by means of internal growth bands and also found that two independent age estimates were in agreement ($r^2 = 0.70$ vs. $r^2 = 0.71$ in the present study) for specimens ranging in age from 2 to 14 years. No other studies on the precision of internal band counts are available for comparison, though external ring counts have been considered in several.

Strayer *et al.* (1981) found *E. complanata* difficult to age using external rings, probably due to the problem of shell erosion described by Ghent *et al.* (1978). Two independent observers disagreed on the ages of many specimens in the 10- to 16-year age-class, and these data had to be discarded. *Anodonta* species have generally fared better. Haukioja and Hakala (1978) compared age estimates made by two people, and independent measurements made by the more experienced person for 100 specimens of *A. piscinalis*. No statistically significant differences between any two pairs of estimates were observed. The maximum difference was 2 years, and 92% of the mussels were assigned the same age in all cases. All specimens were less than 7 years of age. Hanson *et al.* (1988*b*) compared two independent age estimates for 100 specimens of *A. grandis* aged 1–14 years. They found that discrepancies were uncommon and could usually be attributed to the less experienced reader missing the first annulus. We also found external rings counts by two evaluators to be in close agreement for *A. implicata*, but we believe that external rings provide biased estimates of true age. It appears that external ring counts should never be used for *E. complanata*.

Shell length is the morphological feature most frequently used to determine age–size relationships and growth rates of unionid populations (e.g., Ökland 1963; Magnin and Stanczykowska 1971; Haukiuja and Hakala 1978; Hanson *et al.* 1988*a*, 1988*b*). Hinch and Stephenson (1987) selected shell length as a measure of size for *E. complanata* from Ontario lakes because it was highly correlated with shell width and height and exhibited the greatest range of these variables. However, Strayer *et al.* (1981) found that for *E. complanata* from Mirror Lake, New Hampshire, most of the growth in shell length was attained in the first 6–8 years, whereas shell weight increased at a nearly constant rate after 4 years of age. This suggests that shell weight would be the better predictor of age in older mussels of this species. Nalepa and Gauvin (1988) found that both shell length and dry tissue weight increased at a constant rate after age 4 in *L. radiata siliquoidea* from Lake St. Clair, but that shell length was much less variable and therefore predicted age more accurately.

In the present study, correlations between age and both shell measurements were highest for *E. complanata*. This was not unexpected, as we were most confident of our age estimates for this species. When data from the two lakes were combined, shell length appeared to be better correlated with age than shell weight for both *E. complanata* and *A. implicata*. However, for both species, correlations between age and both shell measurements were higher for populations from Powder Mill Beach than Lake Thomas. The reasons for this "lake effect" are unclear; however, we speculate that habitat differences between the two lakes may have been a contributing factor. The Lake Thomas site was exposed, with a steep gradient and coarse substrate, whereas the Powder Mill Beach site was protected, with a gentle slope and uniform sandy substrate. Growth rates of unionids are known to vary with depth, mainly because of water temperature (Ghent *et al.* 1978) but also because of substrate (Nalepa and Gauvin 1988) and food availability (Hanson *et al.* 1988*a*). Unionids are capable of moving distances of tens of metres (Hanson *et al.* 1988*a*), and their normal activities would have exposed them to wider ranges of temperature, current, and substrate conditions in Lake Thomas. This could explain the more variable relationships between age and shell size at this site. Correlations between age and shell measurements for *A. undulata* collected from Powder Mill Beach were similar to those for the other two species from this site, except that shell weight was slightly better correlated with age.

Anodonta implicata grew more rapidly than *E. complanata* at both Lake Thomas and Powder Mill Beach; the slopes of the lines relating growth in shell length or shell weight to age were always steeper for *A. implicata* (Table 2). *Alasmidonta undulata* is a much smaller mussel, with a growth rate at Powder Mill Beach more similar to that of *E. complanata* than *A. implicata* from the same site. Other studies have also shown that *Anodonta* spp. generally grow faster and reach a larger size than *E. complanata*. Using average annual growth in shell length between the ages of 5 and 9 to compare populations, growth rates of 0.30 (this study), 0.43 (Strayer *et al.* 1981), and 0.50 cm/year (Magnin and Stanczykowska 1971) have been reported for *E. complanata*, whereas growth rates of 0.43 (Hanson *et al.* 1988*b*), 0.45 (Ökland 1963), 0.60 (Green 1980), 0.80 (McCuaig and Green 1983), and 1.07 cm/year (this study) have been reported for various species of *Anodonta*. Shell length at age 9 ranged from 6.4 to 9.0 cm for *E. complanata* and from 6.6 to 10.7 cm for *Anodonta* spp. from these populations. Ghent *et al.* (1978) directly compared growth rates of *E. complanata* and *A. grandis* from Lake Bernard, Ontario, using shell height. They found that the widest growth rings in *E. complanata* rarely exceeded 5 mm and were commonly 1–2 mm or even less in older specimens, whereas 10-mm growth increments were common for *A. grandis*.

Anodonta implicata and *A. undulata* do not appear to live as long as *E. complanata*. In this study the oldest *E. complanata* were 17 years of age, the oldest *A. implicata* were 9 years of age, and the oldest *A. undulata* were 7–8 years of age. The maximum life-spans of *E. complanata* from various locations are 12–14 (Magnin and Stanczykowska 1971), 14 (Hinch and Stephenson 1987), 16–18 (Strayer *et al.* 1981), and 18–19 years (Ghent *et al.* 1978). *Anodonta* species appear to be shorter lived by 5–10 years. Maximum ages of 11 (Ökland 1963; Manly and George 1977) and 11–12 years (Hanson *et al.* 1988*b*) have been reported for several species, although Green (1980) found that *A. grandis simpsoniana* lived to 20 years in Shell Lake, Northwest Territories. According to Ghent *et al.* (1978), *A. grandis* in Lake Bernard live 13–14 years, or about 5 years less than co-occuring specimens of *E. complanata*. There is no published life-history information on *A. undulata*.

Elliptio complanata from Powder Mill Beach were much smaller at a given age than those from Lake Thomas, probably due to slower growth rates in the first 5 years of life. Arsenic contamination may have contributed to this difference in growth rates. *Elliptio complanata* from Powder Mill Beach are known to be twice as contaminated with As as those from Lake Thomas, but only slightly more contaminated with Hg (Table 1). There is very little information in the literature on the effects of metals on mussel growth; however, Langston (1980) reported reduced growth rates for the marine bivalve *Scrobicularia plana* exposed to concentrations of As in the sediment (2500 μg/g) which were similar to those at Powder Mill Beach (890–3050 μg/g, Table 1). *Anodonta implicata* may be less sensitive, as their growth rates did not differ significantly between study sites.

In conclusion, age estimates were more precise for *E. complanata*, and models predicting shell length and shell weight from age had the best fit for this species. Difficulties that others have encountered ageing *E. complanata* appear to be due to their attempts to count external rings on specimens that were often badly eroded. We recommend ageing all unionids on the basis of internal bands rather than external rings to avoid the problems of shell erosion, separating crowded rings in old specimens, and distinguishing between disturbance rings and true annuli in light-shelled mussels such as *Anodonta* spp. This study and others have shown that shell length is better correlated with age for some species, whereas shell weight is better correlated for others. The degree of correlation between age and shell size appears to be lower for populations exposed to more variable environmental conditions.

Elliptio complanata may be the best choice as a biomonitor of metal pollution in the Shubenacadie Lakes for the following reasons: (*i*) it is amenable to ageing; (*ii*) it is large enough to provide sufficient material for the analysis of contaminants in individual organisms; (*iii*) it is long lived and slow growing, thus having the potential to accumulate high concentrations of contaminants over time; and (*iv*) it may be sensitive to metal contamination in this system.

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