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Assemblage structure of freshwater mussels (Bivalvia:Unionidae) in rivers with grassy and forested riparian zones

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Abstract. This study was designed to compare unionid assemblages in rivers with grass-dominated and densely treed riparian zones in southwestern Ontario. Environmental variables related to the riparian classes were measured at 24 sites (2 riparian classes × 3 river drainages per riparian class × 4 sites per drainage). We found 17 species in the study basins. Rivers with narrow, grassy riparian zones were characterized by *Pyganodon grandis* and *Strophitus undulatus*, whereas rivers with wider, forested riparian zones were characterised by *Elliptio dilatata, Lampsilis radiata, Lampsilis cardium*, and *Fusconaia flava*. Basin types did not differ in mean number of species per site ($\bar{x}_{grass}$ = 3.75 (SE = 0.708); $\bar{x}_{forested}$ = 4.00 (0.670)). However, a shift towards dominance by a single species was found in grassy rivers where over 60% of individuals in these rivers were *P. grandis*. Riparian classes differ in physical and chemical characteristics with grassy basins receiving greater amounts of solar radiation, having greater daily temperature fluctuations, and higher concentrations of ammonia and total kjeldahl nitrogen than forested basins. Some mussel species appear to be associated with particular riparian types.

Key words: Unionidae, freshwater mussels, riparian, land use, southern Ontario.

The once rich freshwater mussel populations of North America have undergone drastic decline during the past century (Mackie and Topping 1988, Bogan 1993, Parmalee and Hughes 1994). Many species have been driven towards extinction through human activities, either directly through harvesting or indirectly through destruction of aquatic habitat. A reported 73% of North American unionid species are extinct, rare, or imperiled (Allan and Flecker 1993). Although current efforts are shifting towards the conservation of threatened biota, little can be accomplished without a sound understanding of present distributions and the biotic and abiotic factors responsible for governing these distributions.

Historically, records of unionid distributions have included anecdotal notes of habitat preferences; these notes have usually centred on microhabitat characteristics and include such factors as current velocity, water depth, and substrate type (e.g., Detweiler 1918, La Rocque and Oughton 1937). Rigorous testing of these microhabitat preferences has been rare and the results have been, at best, mixed (Strayer and Ralley 1993).

In a recent examination of unionid habitat preferences, Strayer (1993) emphasized the usefulness of macrohabitat variables, such as stream size and gradient, hydrologic variability and physiography, as predictive agents. The predictive power of these macrohabitat variables has proven to be more effective than microhabitat variables. For example, Di Maio and Corkum (1995) showed that distinct mussel communities can be predicted on the basis of the hydrological status of a stream.

The usefulness of other large-scale habitat characters has been demonstrated at a number of differing scales. For example, Ross (1963) and Corkum (1991, 1992) illustrated the broad-scale importance of climax vegetation and land-use characters in predicting the spatial distribution of lotic invertebrates. Sallenave and Day (1991) showed that life history traits of several *Hydropsyche* species were related to tillage practices on the adjacent land. The link between terrestrial land use and the biotic responses observed in aquatic communities lies in the dynamic processes that occur at the land–water boundary. Although this boundary represents the extreme limits of 2 seemingly distinct habitat types, exchanges across it can drastically affect either habitat. Riparian buffer zones may be defined as planted or native vegetation downslope of cropland or animal pasture, adjacent to the watercourse (Dillaha et al. 1989) and can act in many ways to limit the potentially harmful effects of human activity on aquatic habitats (Castelle et al. 1994). This buffering includes the moderatation of temperature fluctuations through shading (Budd et al. 1987), the removal of sediment from overland flow before it enters the main channel (Young et al. 1980), and the regulation of nutrients and metal levels entering the water body (Peterjohn and Correll 1984).

Fuller (1974) summarized the effects of many land-derived elements on freshwater mussels. Although the temperature requirements of many unionids are not fully understood, a wide variety of responses has been attributed to changes in temperature, including egg mass abortion, dulled glochidial response, repressed development of the digestive system, changes in oxygen requirements, and death (Fuller 1974).

The ability of riparian zones to act as sediment and nutrient filters also may affect mussel assemblages, because sediment not only impairs light penetration and disrupts phototaxic responses (McMahon 1991) but also may clog the filtration apparatus and lead to death (Fuller 1974). Although the effect of nutrient loadings on mussel assemblages has been much less studied, some examples do exist. Bauer (1988) reported that juvenile survival and establishment of the unionacean *Margaritifera margaritifera* (L) were negatively associated with phosphate loadings, whereas adult survival was negatively correlated with nitrate loadings.

The purpose of the present study was to examine the relationship between the riparian zone and the unionid assemblage in some agricultural drainage basins in southwestern Ontario. Rivers were selected from 1 of 2 a priori riparian classes (grassy or forested). We wanted to see if distinct mussel assemblages could be associated with each of the riparian classes and which environmental variables were most important in describing these associations.

Methods

Study sites

We selected 6 agricultural drainage basins in southwestern Ontario: 3 with forested buffer strips and 3 with grassy riparian zones (Fig. 1). All drainage basins contained predominantly agricultural land with less than 30% forest cover in any 1 basin. Rivers were initially categorized by eye: rivers in the forested category had densely treed riparian zones and those in the grassy category had either no riparian vegetation (i.e., plowed to edge of the channel) or only small grassy riparian zones. Later we confirmed this categorization using direct measurements of the riparian zone. Basins with forested riparian zones were the Ausable River, Dingman Creek, and the Saugeen River. Basins with grassy riparian zones were the Avon River, McGregor Creek, and Whirl Creek. Drainage basins were selected using Ontario Ministry of Natural Resources (1983a–e) land use reports and 1:50,000 topographic maps. Sample sites were selected on the basis of accessability, wadeability, and the presence of a mussel assemblage during preliminary sampling on 3–5 August 1994. We sampled 4 sites in each of the 6 drainage basins.

Although it is difficult to obtain independence of sites along a river, we attempted to ensure independence of study sites by requiring 1 tributary and a minimum distance of 2 km along the river channel between sites. Because of the sedentary nature of adult mussels (e.g., Balfour and Smock 1995) and this minimum distance, we feel that our sites represent independent assemblages with no exchange of individuals between sites over the temporal scale of our study.

Mussel collection

Mussels were sampled using a catch-per-unit-effort approach because the emphasis of our study was to determine the species composition of each site. Although quadrat sampling has been shown to be effective at quantifying unionid densities, catch-per-unit-effort techniques provide a more complete assessment of rare and uncommon species (Strayer et al. 1996, Vaughn et al. 1996). Mussel assemblages were sampled once per site between 23 August and 8 September 1994. We sampled while wading and feeling the substrate for individuals for a period of 60 min. Each site was searched beginning at the downstream end and progressing upstream while moving across the site from bank to bank such that all potential habitat was searched. The 60-min search time did not include time required to identify mussels and process voucher specimens (see below).

We attempted to identify each mussel to species in the field. Individuals that could not be positively identified in the field were taken to the laboratory in 75% ethanol for identification. In addition, the 1st individual of each species encountered at a site was collected as a voucher

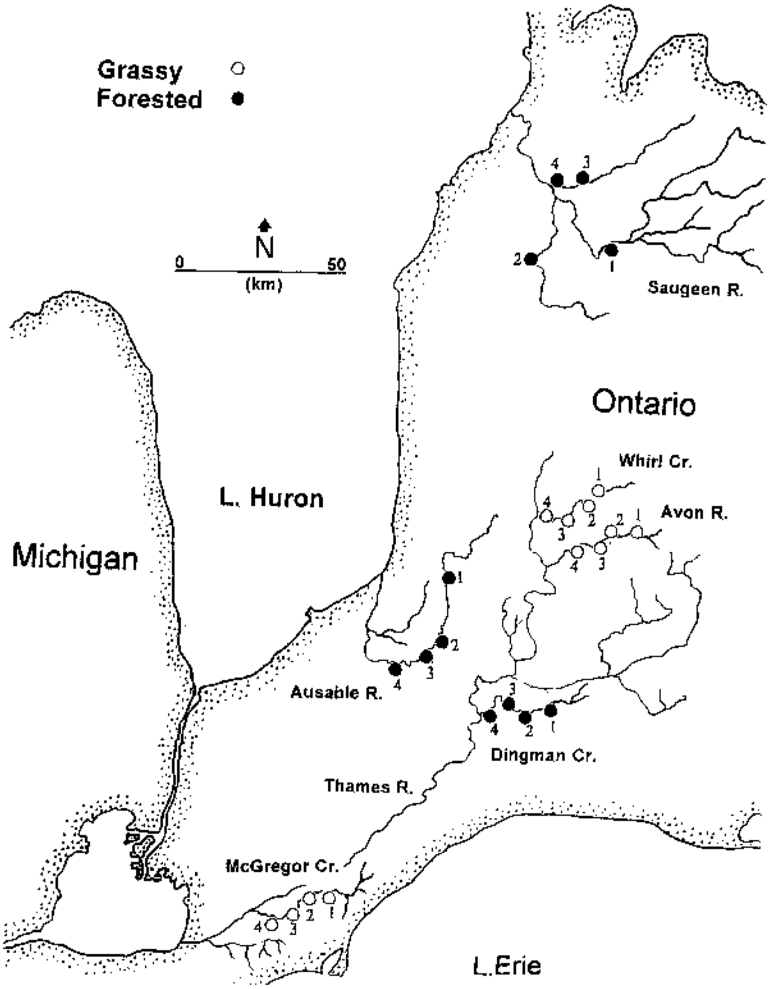

FIG. 1. Location of study sites.

specimen for positive identification. Voucher specimens have been deposited at the Royal Ontario Museum in Toronto (collection #1996-003). Mussel nomenclature follows Turgeon et al. 1988 and Hoeh 1990.

Environmental variables

All sediment, shading, and water chemistry data except nutrients were collected at the same time as mussels were sampled, between 23 August and 8 September 1994. Nutrients were sampled on 10 August 1995.

Riparian characteristics.—Although drainage basins were assigned on an a priori basis to 1 of the 2 riparian classes, terrestrial variables were measured in the field to further describe these classes. The width of the riparian zone was defined as the perpendicular distance from the water's edge to the agricultural field. At each site, the riparian width (measured to the nearest 0.1 m) was measured at 6 locations. On each of the left and right banks, 3 widths were measured—1 each at the upstream and downstream extremes and 1 midway between.

At each of the 6 locations of riparian width measurements, 2 measures of terrestrial slope were recorded using a Brunton Pocket Transit (model 5008). The 1st measure, valley slope, was designated as the slope of the land from the water's edge to bankfull depth. The 2nd measure of slope was the plain slope and was defined as the slope from the bankfull depth to the distal edge of the riparian zone.

TABLE 1. Relative abundance of each unionid species found in the study area.

Species	Total	Grassy	Forested
Pyganodon grandis (Say 1829)	0.625	0.625	0.01
Strophitus undulatus (Say 1817)	0.458	0.097	0.01
Lasmigona compressa (Lea 1829)	0.416	0.051	0.0
Lasmigona complanata (Barnes 1823)	0.333	0.07	0.183
Amblema plicata (Say 1817)	0.292	0.037	0.269
Lampsilis siliquoidea (Barnes 1823)	0.292	0.002	0.021
Lasmigona costata (Rafinesque 1820)	0.250	0.004	0.062
Elliptio dilatata (Rafinesque 1820)	0.208	0.0	0.205
Alasmidonta marginata (Say 1829)	0.208	0.0	0.067
Fusconaia flava (Rafinesque 1820)	0.208	0.04	0.12
Leptodea fragilis (Rafinesque 1820)	0.125	0.051	0.012
Ligumia recta (Lamarck 1819)	0.125	0.0	0.062
Potamilus alatus (Say 1817)	0.125	0.018	0.0
Ptychobranchus fasciolaris (Rafinesque 1820)	0.083	0.0	0.014
Lampsilis cardium (Barnes 1823)	0.083	0.0	0.069
Actinonaias ligamentina (Barnes 1823)	0.083	0.0	0.005
Quadrula quadrula (Rafinesque 1820)	0.042	0.004	0.062

Water chemistry data.—Rivers with riparian vegetation have lower levels of suspended sediments and nutrients than rivers with disturbed riparian zones (Castelle et al. 1994). Since sediment and nutrients have been related to unionid distributions, we chose to examine differences in our study basins. We collected 3 water samples in 500-mL Nalgene bottles for estimates of suspended sediment and ash free dry mass (AFDM). Suspended sediment and AFDM samples were filtered in the field through Whatman glass microfibre filters (4.7 cm) using a Nalgene hand-held vacuum pump. Samples were held on ice in the field and kept frozen in the laboratory until processing could be completed. The change in weight from heating at 103°C for 24 h to heating at 550°C for 1 h was determined as the AFDM of the sample. Conductivity was measured in the field using an Oakton hand-held conductivity meter (model WD-35607-10); pH was field measured using an Oakton p-HTestr 2 (model 35624-20).

Triplicate 1000-mL water samples were collected 10 August 1995 for determination of nitrate, nitrite, and soluble reactive phosphate (SRP) concentrations. Nitrate and nitrite samples were analysed through cadmium reduction at the Agriculture Canada research station in Harrow, Ontario. SRP was determined using the molybdenum blue method of Wetzel and Likens (1991) at the University of Windsor. In addition, monthly mean nutrient concentrations (nitrate, nitrite, ammonia, total kjeldahl nitrogen, total phosphate) were obtained from monitoring stations of the Ontario Ministry of the Environment and Energy within the study basins.

Shading and temperature.—A riparian canopy shades the river channel and prevents high water temperature. To quantify this effect within our study rivers, we measured canopy overhang at each site with a Solar Pathfinder® (Solar Pathfinder, Hartford, South Dakota). Using the riparian profile and the tables provided with the Solar Pathfinder®, we were able to estimate the total incident solar radiation at the water surface during each calendar month for each site. Solar Pathfinder® measurements were taken at a mid-river point equidistant from the upstream and downstream boundaries of the site.

Temperature data were obtained for 3 grassy and 2 forested basins, at the farthest downstream site in each drainage basin, using Hobo XT Temperature Loggers. Temperature data for the 3rd forested basin, the Ausable River basin, was not available because the logger was lost during fall spates. Temperature loggers were placed at the substrate surface and anchored to 1-m-long galvanized rods driven into the substrate; they were installed on the same day as mussel assemblages were sampled but only after all other sampling had been completed to eliminate the risk of contaminating water samples. Temperature values were recorded every

100 min for a duration of about 115–120 d (September–December) (exact durations differed among rivers).

Statistical methods

Multiple Discriminant Analyses (SPSS Inc. 1983; Norusis 1985) were conducted using log (x + 1.1) transformed species abundance data and the riparian data. The log (x + 1.1) transformation was used to eliminate zeros from the transformed data set which may cause errors with the statistical package used. This multivariate technique allowed the prediction of group membership (grassy or forested) on the basis of species abundance (1st analysis) and terrestrial riparian data (2nd analysis). The 1st analysis was used to test our hypothesis that mussel distributions are linked to riparian conditions whereas the 2nd analysis, based solely on the terrestrial measures of slope and riparian width, provided verification of a priori placements derived from land-use maps and visual inspections. Wilcoxon sign-ranked nonparametric tests were used to test for differences in water chemistry between grassy and forested rivers, and repeated measures ANOVA was used to examine differences in solar radiation between riparian classes over 1 y.

Results

Mussel species

We observed 875 mussels at the 24 sampling sites. Of these mussels, 455 were in the grassy riparian basins; 420 in forested sites. We found 17 species (Table 1): 11 species in the grassy basins and 14 in the forested. Eight species were common to both riparian types. The mean number of species did not differ significantly between the 2 habitats ($F_{(1,22)} = 0.07$, $p > 0.05$).

Individual species showed distinct differences in relative abundance in the 2 habitat types (Table 1). *Pyganodon grandis* represented 62.5% of all mussels in grassy basins, but only 1% of mussels in forested basins.

Only the 12 species found to occur in more than 1 basin were included in the analysis, as species limited to 1 basin provide no power to discriminate between basins. We found that 100% of sites were correctly classified using mussel species abundances ($\chi^2 = 36.47$, df = 12, p = 0.0003). All grassy sites had positive scores for the species discriminant function, whereas all forested sites had negative scores (Fig. 2). Six species were significantly more abundant in one or the other riparian type: *P. grandis* ($F_{(1,22)} = 109.1$, $p < 0.001$), *Strophitus undulatus* ($F_{(1,22)} = 6.926$, $p < 0.05$), *Fusconaia flava* ($F_{(1,22)} = 5.336$, $p < 0.05$), *Lampsilis siliquoidea* ($F_{(1,22)} = 4.897$, $p < 0.05$), *Lampsilis cardium* ($F_{(1,22)} = 5.294$, $p < 0.05$) and *E. dilatata* ($F_{(1,22)} = 6.312$, $p < 0.05$). *P. grandis* and *S. undulatus* were characteristic of grassy sites (positive correlations with species DF1) and *F. flava*, *L. siliquoidea*, *L. cardium* and *E. dilatata* were characteristic of forested sites (negative correlations with species DF1) (Table 2).

Environmental variables

Forested basins had significantly steeper plain and valley slopes with wider riparian buffer strips (Table 3). No differences were detected for pH, conductivity, suspended sediment, or AFDM (Table 3).

The 2nd Multiple Discriminant Analysis, of 3 terrestrial variables, correctly classified 85% of sites ($\chi^2 = 97.66$, df = 3, $p < 0.0001$). All 12 grassy sites had negative scores for the environmental discriminant function, whereas only 9 forested sites had positive scores (Fig. 2). Positive correlations for all 3 variables with the environmental DF1 (Table 4) indicate increasing values for all variables at forested sites in comparison to grassy sites.

Grassy sites received a greater proportion of the available incident solar radiation during each calendar month (rmANOVA $F_{(11,12)} = 3.11$, $p < 0.05$) (Fig. 3). From April to September, grassy sites received >90% of the possible incident radiation, whereas forested sites received 50–65% during this same period. Mean monthly water temperature did not differ significantly between the 2 riparian classes although grassy sites had slightly higher temperatures. Daily temperature fluctuations were significantly greater at grassy sites (4.30°C) than forested sites (2.47°C) ($F_{(1,86)} = 27.23$, $p < 0.001$).

No significant differences were found between grassy and forested sites for nitrates ($F_{(1,70)} = 0.290$, $p > 0.05$), nitrites ($F_{(1,70)} = 0.623$, $p > 0.05$), or SRP ($F_{(1,70)} = 0.223$, $p > 0.05$) collected on 10 August 1995. However, water quality data obtained from the Ontario Ministry of the Environment and Energy monitoring sta-

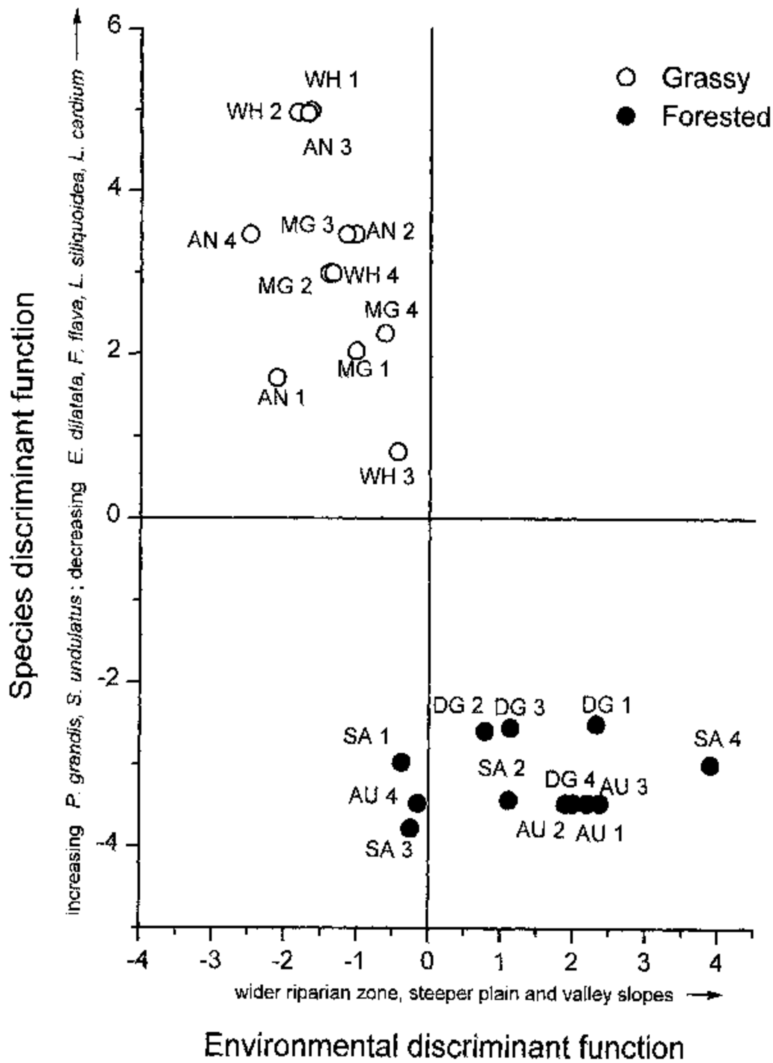

FIG. 2. Multiple Discriminant Analyses on the basis of unionid species abundances (y axis) and physical riparian characteristics (x axis). A priori riparian classification is represented by open (grassy sites) and closed (forested sites) symbols. (AN—Avon R., MG—McGregor Cr., WH—Whirl Cr., AU—Ausable R., DG—Dingman Cr., and SA—Saugeen R.)

tions within the study area (3 stations in grassy basins, 6 stations in forested basins) revealed differing concentrations of circulating nutrients within the rivers of the 2 riparian classes on an annual basis (Table 5). Grassy rivers had higher annual mean concentrations of ammonia nitrogen ($F_{(1,7)}$ = 7.36, p = 0.03) and total kjeldahl nitrogen ($F_{(1,7)}$ = 7.58, p = 0.028) than forested rivers. Concentrations of nitrates ($F_{(1,7)}$ = 5.22, p > 0.05), nitrites ($F_{(1,7)}$ = 0.10, p > 0.05), and phosphates ($F_{(1,7)}$ = 4.99, p > 0.05) again did not differ significantly between the 2 riparian classes.

Discussion

We found that some unionid species occurred more frequently in rivers with forested riparian zones, whereas others were more abundant in rivers with open grassy riparian zones. These species-specific differences in distributions coincided with other large-scale habitat changes,

TABLE 2. Results of Multiple Discriminant Analysis on the basis of the log(x+1.1) transformed relative abundances of the 12 unionid species found to occur in more than 1 basin.

	Species DF1	
Species	Coefficient	Correlation
Pyganodon grandis	1.139	0.752
Strophitus undulatus	−0.003	0.189
Lasmigona compressa	0.622	0.100
Lasmigona complanata	0.414	0.007
Amblema plicata	−0.413	−0.092
Lasmigona costata	−0.153	−0.099
Actinonaias ligamentina	−0.183	−0.107
Alasmidonta marginata	0.284	−0.119
Lampsilis siliquoidea	0.359	−0.159
Lampsilis cardium	0.031	−0.166
Fusconaia flava	−0.078	−0.166
Elliptio dilatata	−0.494	−0.181
	$\chi^2 = 36.472$	
	$p = 0.0003$	

including shading, temperature regime, and circulating nutrient concentrations.

Although no overall differences in species numbers were detected between our basin types, we observed a trend towards much higher numbers of *P. grandis* in basins with grassy riparian zones. The reason for this shift towards dominance by *P. grandis* is likely the result of a combination of the filtering capacity of the riparian zone and the ecological relationships of this species. *P. grandis* is one of the most common unionid species in this geographic area and reportedly possesses wide sediment and flow tolerances (Clarke 1981) that make it ideally suited to inhabit rivers with high agricultural runoff.

Southwestern Ontario used to be forested (Riley and Mohr 1994); however, much of the forested watersheds were cleared to permit agriculture and are now characterised by open, unshaded channels. The clearing of forests and the associated removal of riparian vegetation can have important implications to the thermal and chemical properties of aquatic systems. The removal of the riparian canopy may result in elevated mean temperatures as well as greater daily and seasonal temperature fluctuations (Budd et al. 1987). For the 6 drainages in southwestern Ontario examined in this study, we showed that the thermal regime is linked to the presence or absence of the riparian buffer strip. Rivers with forested riparian zones tend to have lower mean monthly water temperatures than rivers with grassy riparian zones and to have daily temperature fluctuation cycles that are significantly damped by the shading properties of the riparian vegetation. Our study was conducted during the fall when temperature differences between the basins were near a minimum, yet significant differences still existed. The larger differences in temperature during summer may be important in structuring mussel assemblages through establishment and survival of juveniles and deserve further attention (Hanson et al. 1988, McMahon 1991).

In addition to the thermal differences, we found that rivers passing through open agricultural lands had significantly higher annual mean concentrations of NH_4-N and TKN than rivers with forested margins. Although the literature regarding the importance of nutrient levels to the growth and establishment of unionids is limited, there is a small amount of correlative evidence. Starret (1971) reported an absence of unionids from stretches of the Illinois River with ammonia levels in excess of 6.0 ppm. Although Starret (1971) erroneously attributed this absence to effects on host fish species, Fuller (1974) noted the possibility of a more direct effect.

Maximum concentrations of ammonium detected during the present study were lower (approximately 1/4) than those reported by Starret (1971); however, concentrations observed in grassy rivers averaged 17 times greater than those in forested rivers. While these levels may be below those that result in complete loss of the unionid community, there is the potential for species-specific metabolic suppression resulting in the assemblages observed in grassy and forested rivers. In contrast, concentrations of nitrate, nitrite and phosphate, which have been shown to aid or hinder the growth and survival of other bivalves (Fuller 1974, Bauer 1988, 1992), appear unrelated to the distributions observed during this study. However, present chemical concentrations may be very different from conditions when mussels colonized these rivers and care should be taken in interpreting these results.

Southern Ontario possesses the richest and most diverse unionid fauna in Canada (Clarke 1981), yet many of the rivers of the area have

TABLE 3. Mean (±1 SE) values for environmental data collected from grassy and forested sites. Significance values are based on a comparison of mean values for grassy and forested basins using ANOVA (plain slope, riparian width, and valley slope) or Wilcoxon sign-ranked non-parametric tests (pH, conductivity, suspended sediment, and ash free dry mass).

	Grassy	McGregor Creek	Whirl Creek	Avon River	**Forested**	Dingman Creek	Ausable River	Saugeen River	Significance
Plain slope (%)	**3.1**	3.8	3.1	2.3	**13.7**	5.9	16.8	18.2	$p < 0.01$
	(0.85)	(1.04)	(3.36)	(3.17)	**(3.38)**	(1.59)	(14.77)	(14.01)	
Riparian width (m)	**16.07**	13.9	22.51	11.80	**39.49**	37.17	44.67	36.63	$p < 0.01$
	(2.726)	(3.34)	(9.34)	(9.06)	**(3.370)**	(15.06)	(16.83)	(8.86)	
Valley slope (%)	**31.1**	29.5	27.6	36.4	**37.0**	52.5	27.5	30.9	$p < 0.05$
	(1.81)	(5.77)	(2.90)	(4.86)	**(4.15)**	(9.61)	(18.25)	(9.95)	
pH	**8.55**	8.35	8.95	8.35	**8.50**	8.35	8.50	8.65	ns
	(0.111)	(0.114)	(0.384)	(0.087)	**(0.051)**	(0.166)	(2.759)	(0.087)	
Conductivity (µS/cm at 25°C)	**570.6**	753.3	383.3	575.3	**581.8**	790.5	466.7	488.0	ns
	(45.89)	(10.20)	(25.07)	(16.90)	**(48.67)**	(47.35)	(306.36)	(93.58)	
Suspended sediment (mg/L)	**28.0**	52.5	8.31	22.9	**26.7**	31.9	43.7	4.4	ns
	(6.25)	(10.56)	(3.34)	(12.30)	**(7.58)**	(14.84)	(18.37)	(2.39)	
Ash free dry mass (mg/L)	**2.9**	4.4	2.8	7.1	**3.8**	2.9	7.2	1.2	ns
	(0.85)	(2.31)	(1.34)	(2.61)	**(0.95)**	(2.00)	(2.84)	(0.57)	

TABLE 4. Results of Multiple Discriminant Analysis on the basis of terrestrial variables found to differ between riparian classes.

Variable	Environmental DF1 Coefficient	Correlation
Riparian width	0.8798	0.8194
Plain slope	0.4309	0.4531
Valley slope	0.4228	0.2000
	$\chi^2 = 97.658$	
	$p < 0.0001$	

TABLE 5. Mean annual (±1 SE) levels (mg/L) of nutrients in grassy and forested drainages of southwestern Ontario. Data obtained from Ontario Ministry of the Environment and Energy monitoring stations. Figures based on 11 mo (January–November) and 3 (grassy) or 6 (forested) monitoring stations.

	NH_3-N	NO_2-N	NO_3-N	Total kjeldahl nitrogen	Total phosphorus
Grassy	1.41	0.248	4.13	1.32	0.040
	(0.541)	(0.052)	(0.761)	(0.236)	(0.012)
Forested	0.084	0.0326	3.13	0.79	0.022
	(0.025)	(0.005)	(0.582)	(0.061)	(0.005)

undergone significant declines in terms of both species and numbers of individuals during recent years (Mackie and Topping 1988). The results of our study support the idea that increasingly agricultural activity is resulting in a shift towards dominance by a single common species in rivers of open riparian zones, with *P. grandis* representing over 60% of individuals in these rivers. Agricultural activity and loss of riparian vegetation appear to be major threats to mussels (Hoggarth et al. 1995). The relationship between the physical properties of the streamside riparian zone and the structure and composition of the unionid community should prove beneficial for the design and implementation of effective conservation methods for these threatened organisms.

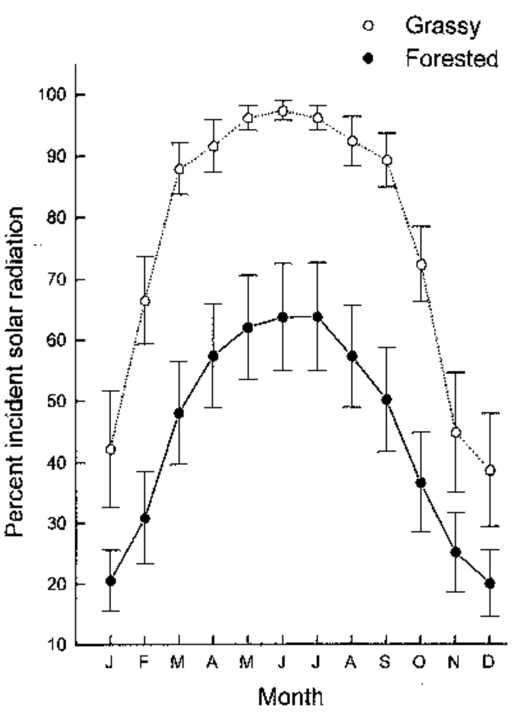

FIG. 3. Percentage of available solar radiation reaching the water surface estimated using the Solar Pathfinder®. Data are means (n = 12) ± 1 SE.

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