RESEARCH

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Lakes, Wetlands, and Streams as Predictors of Land Use/Cover Distribution

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ABSTRACT / The importance of the surrounding landscape to aquatic ecosystems has been well established. Most research linking aquatic ecosystems to landscapes has focused on the one-way effect of land on water. However, to understand fully the complex interactions between aquatic and terrestrial ecosystems, aquatic ecosystems must be seen not only as receptors of human modification of the landscape, but also as potential drivers of these modifications. We hypothesized that the presence of aquatic ecosystems influences the spatial distribution of human land use/cover of the nearby landscape (≤1 km) and that this influence has changed through time from the 1930s to the 1990s. To test this hypothesis, we compared the distribution of residential, agricultural, and forested land use/cover around aquatic ecosystems (lakes, wetlands, and streams) to the overall regional land use/cover proportion in an area in southeast Michigan, USA; we also compared the distribution of land use/cover around county roads/highway and towns (known determinants of many land use/cover patterns) to the regional proportion. We found that lakes, wetlands, and streams were strongly associated with the distribution of land use/cover, that each ecosystem type showed different patterns, and that the magnitude of the association was at least as strong as the association with human features. We also found that the area closest to aquatic ecosystems (<500 m) was more strongly associated with land use/cover distribution than areas further away. Finally, we found that the strength of the association between aquatic ecosystems and land use/cover increased from 1938 to 1995, although the overall patterns were similar through time. Our results show that a more complete understanding is needed of the role of aquatic ecosystems on the distribution of land use/cover.

It is well understood that aquatic ecosystems are strongly linked to the surrounding landscape and should not be studied exclusive of their environmental setting (Hynes 1975, Allan and Johnson 1997, Kratz and others 1997). To date, most studies on land–water interactions have focused on the one-way interaction from land to water by examining the transport of terrestrial derived materials to aquatic ecosystems (Peterjohn and Correll 1984, Osborne and Wiley 1988, Soranno and others 1996). In particular, there has been much research on the effect of land use on streams (Dillon and Kirchner 1975, Allan and others 1997, Herlily and others 1998), lakes (Stemberger and Lazorchek 1994, Siver and others 1999), and wetlands (Mensing and others 1998, Lehtinen and others 1999). However, to understand fully the complex interactions between aquatic and terrestrial ecosystems, aquatic ecosystems must be seen not only as receptors of human modification of the landscape, but also as potential drivers of these modifications (Riera and others 2001).

Several different approaches have been used to try to quantify how people value and use specific types of land in relation to aquatic ecosystems from the disciplines of sociology, economics, and geography. Some sociological methods use surveys to assess people's attitudes and values towards specific features on the landscape (Ryan 1998, Streever and others 1998, Berrens and others 2000). For example, Ryan (1998) showed people pictures of riparian areas with different amounts and types of vegetated and unvegetated riparian zones and found that people ranked the vegetated riparian zones highest. This type of research provides information on what people prefer, but may not describe what people actually do with their riparian land. Economic research methods, on the other hand, attempt to estimate the economic value of aquatic ecosystem goods and services through the use of hedonic pricing, travel cost, and contingent valuation methods (Wilson and Carpenter 1999). These studies have shown that property values are elevated near lakes, wetlands, and streams, most likely because people place a high value on living near aquatic ecosystems for aes-

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thetic and recreational reasons (David 1968, Siderelis and Perrygo 1996, Doss and Taft 1996, Mahan and others 2000). Many of these types of studies use the market value of land near aquatic ecosystems to express the value people place on a given ecosystem, but may not provide information on the how the land is actually used. Finally, historical methods develop detailed case histories of particular regions to examine the close interplay between people, land use change, and aquatic ecosystems (Prince 1997, Riera and others 2001). Although all of the above approaches have improved our understanding of the values that people place on aquatic ecosystems and the potential influence on land use change, few studies have taken an empirical approach to quantify how these values translate into actual distributions of land use around aquatic ecosystems. Quantifying how lakes, wetlands, and streams influence the distribution of land use around them should improve our understanding and ability to model future land use change. In addition, the above research suggests that each type of aquatic ecosystem is valued differently, although there have been few studies examining all three concurrently (but see Wilson and Carpenter 1998).

Many drivers of both broad- and fine-scale patterns in land use have been used to model present and future land use change (Burgess 1967, Hart 1976). Broad-scale (10–1000 km) predictors of land use include natural features such as geology, climate, water supply, presence of navigable rivers, and topography and human features such as the presence of highways, industry, school districts, and urban centers. At finer scales (<10 km), additional predictors of land use that have been incorporated into land use change models include natural features such as slope and vegetation as well as human features such as distance to towns and roads, land use regulations, and age of farmers (Turner and others 1996, Veldkamp and Fresco 1996, Levia and Page 2000). However, incorporating predictor variables related to aquatic ecosystems, such as the presence of and the distance to aquatic ecosystems, has only rarely been done. For example, McGranahan (1999) found that a "natural amenities" index, which included water area, was strongly related to rural county population change in the United States from 1970 to 1996. In regions with even moderate densities of aquatic ecosystems, ignoring them is likely to lead to errors in predicted land use change.

The fact that aquatic ecosystems have not been widely included in models of land use change is surprising because there is strong evidence that humans highly value aquatic ecosystems and the services they provide (Postel and Carpenter 1997, Zedler and others 1998). One reason that aquatic ecosystems have been overlooked may be due to the fact that few studies have quantified their effect on land use distribution. For example, while we know that lakes attract residential development, the magnitude of this effect is not well understood. Is it limited to the lake riparian zone itself, or does it carry on beyond the riparian zone? For example, Schnaiberg and others (2002) found that 61% of the residential development in a northern Wisconsin county occurred within 100 m of lake shorelines. A second possible explanation for why aquatic ecosystems have been overlooked is that attitudes towards aquatic ecosystems have changed, resulting in different associations between aquatic ecosystems and land use through time that have not been well quantified. For example, historically, riparian areas of larger streams and rivers attracted industrial uses, while navigable rivers and large lakes attracted the development of major urban centers (Cronon 1983, Postel and Carpenter 1997). However, due to a more recent recognition of the need to preserve stream water quality, stream riparian zones are now often preserved in natural land cover (Kleiman and Erickson 1996). Even more dramatic is the change in attitude towards wetlands. In the past, wetlands were considered wastelands and drained for agricultural use, now wetlands are recognized for their value in improving water quality and their intrinsic value as ecosystems (Prince 1997, Zedler and others 1998).

Our study was designed to consider some of the above gaps in our understanding of the relationship between aquatic ecosystems and land use distribution. We examined a region of southeast Michigan, USA, with mixed land use/cover to test two hypotheses. First, we hypothesized that aquatic ecosystems influence the fine-scale distribution of residential, agricultural, and forested land use/cover to a similar degree as known drivers of land use/cover such as human features (e.g., towns and county roads/highways). In particular, we expected that the effect of aquatic ecosystems extends beyond their riparian zones (defined as the 100 m buffer around aquatic ecosystems) to as far as 1 km, but that lakes, wetlands, and streams will each influence land use cover differently because of their different values and the different ecosystem services provided to humans. Second, we hypothesized that the relationship between land use/cover and aquatic ecosystems has changed through time from 1938 to 1995. To test these hypotheses, we developed an approach to quantify the distribution of land use/cover within 1 km of aquatic ecosystems (lakes, wetlands, and streams) and human features (county roads/highways and towns). This method determines whether the distance to certain landscape features (aquatic ecosystems and human features) is significantly associated with the distribution of different land use/cover categories by comparing the land use/cover proportion within distance buffers to the overall study site land use/cover proportion.

Study Site

Our 1720 km^2 study site is located within the Huron River watershed in southeast Michigan, USA. The surface topography of the region is characteristic of a glaciated landscape, with glacial moraines, till plains, and outwash deposits (Hay-Chmielewski and others 1995). European human settlement began in the 1700s. By the 1800s, agriculture was the dominant land use in the region (Hay-Chmielewski and others 1995). Since then, extensive land conversion has produced a mixture of residential, agricultural, and natural land use/covers (Figure 1). The northern region of the area contains a dendritic pattern of streams and extensive lake and wetland areas (Figure 2A). The study site has nine towns of varying size and a dense network of county roads and highways characteristic of development patterns in the Midwest United States (Figure 2B).

Methods

Landscape and Aquatic Ecosystem Data

All data were compiled in a geographic information system (GIS) database. The 1995 land use/cover coverage was created by classifying color aerial photographs (Huron River Watershed Council, unpublished data). The 1938 land use/cover coverage was created using georeferenced black-and-white aerial photographs and a 1985 classified land use/cover layer obtained from the Michigan Resource Information Service (MIRIS 2000, Rutledge 2001). The land use/cover data were classified using level I classes in the Anderson Classification scheme (Anderson and others 1976), which includes: urban, agriculture, nonforested vegetation (i.e., grasses and shrubs), forest, water, and wetlands. Because the urban category was approximately 70% residential land use/cover, we use the term “residential” for this land use/cover. The minimum resolution of the original MIRIS land use/cover data is approximately 1 ha. For all buffer analyses, we removed areas from our study site that were within town boundaries (7% of the total study area) and that were publicly owned (4% of the study area) because there should not have been any change in residential, agricultural, or forested land use/cover in these areas. These areas were removed before the buffers were created. The publicly owned land was almost all forested land in state, municipal, or county parks. Public lands were identified from a quarter section ownership coverage created by the Land and Minerals Division of the Michigan Department of Natural Resources.

Separate coverages were created for lakes, wetlands, and streams. These were used for the buffer analysis for both time periods. The lake and wetland coverages came from the 1995 land use/cover coverage and included ecosystems that were greater than 1 ha. The wetland coverage included only depressional wetlands (nonforested wetlands). We also removed riparian wetlands (wetlands immediately adjacent to lakes and streams) from the wetland coverage. The above wetlands were only removed from the wetland aquatic feature coverage, not the land use/cover coverage. The stream coverage came from a 1972 land use/cover coverage for which extensive editing had been done to correct shoreline delineation and to include small streams [down to approximately second order (Strahler 1964)]. For lakes and streams, there were only minor changes in their number, size, and distribution from 1938 to 1995 (Walsh 2000), so we assumed that lake and stream presence and location were constant across the 57-year study period. However, wetlands did change through time. The total area of depressional wetlands decreased by 32% from 1938 to 1995; thus we used only wetlands that existed from 1938 to 1995 in our buffer analysis. Within the final three aquatic coverages, there were 445 lakes, 1280 depressional wetlands, and 104 stream segments (Table 1).

We also created separate coverages of the county roads/highways and town data that were used for both time periods (Table 1). Roads and towns likely changed from 1938 to 1995, and because there are no historical data available for these coverages, our estimates are only approximate. The county roads/highway coverage and the towns coverage were obtained from MIRIS (MIRIS 2000). The county roads/highways coverage included highways, limited access highways, and county roads. The towns coverage included boundaries around towns and cities within the watershed.

Buffer Analysis

For all analyses, we created five separate buffer coverages for each landscape feature (lakes, wetlands, streams, towns, and county roads/highways). We created ten concentric 100-m buffers around each landscape feature, and performed the following analyses in ArcView 3.2 (ESRI), described here for lakes only. Unique buffers were created consecutively beginning with the 100-m buffer closest to each lake and extend-

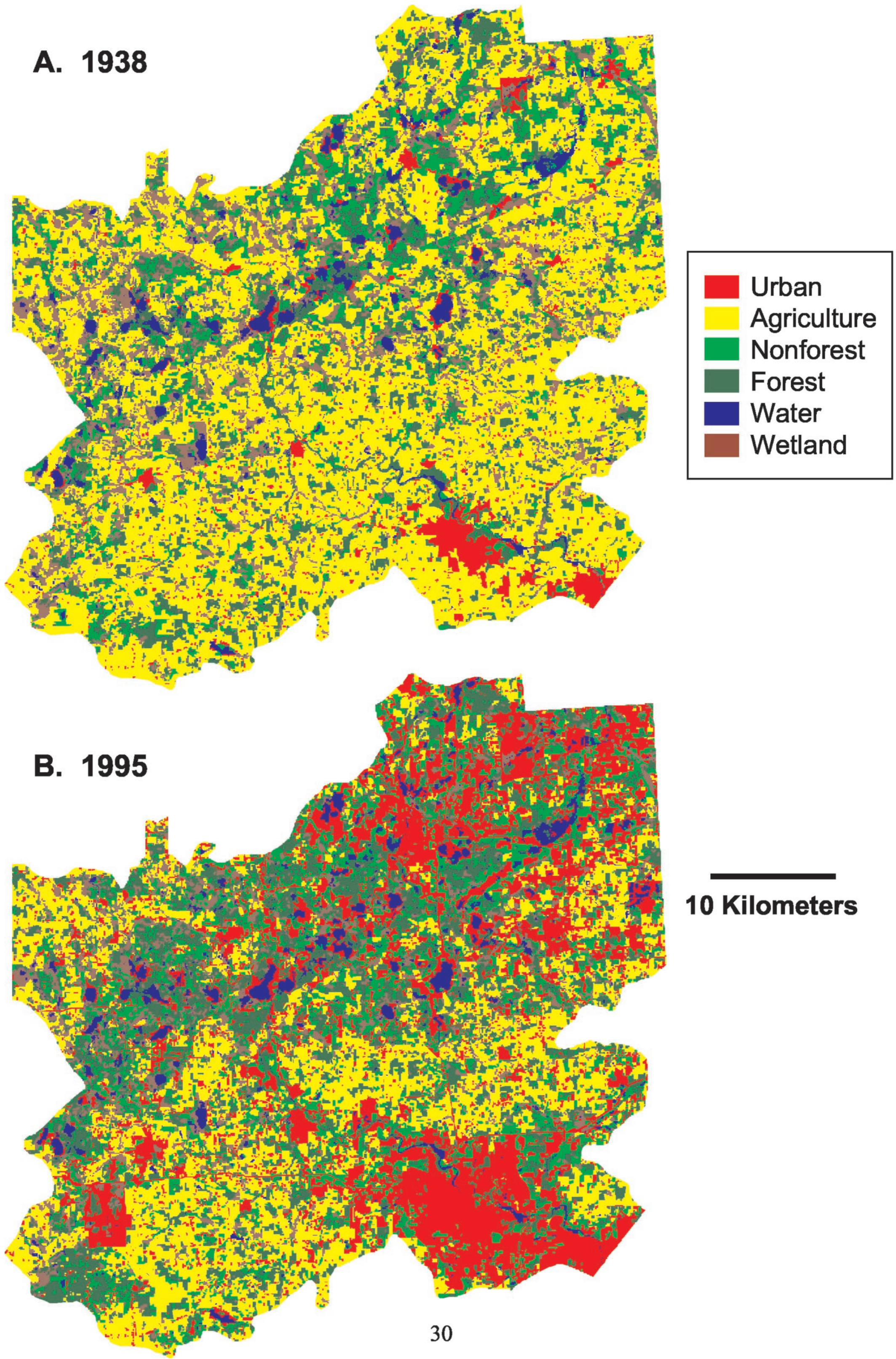

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Figure 1. Land use/cover in the study area for 1938 (**A**) and for 1995 (**B**). Nonforest vegetation includes areas classified as grassland and shrubland. The wetland category is made up of both forested and nonforested wetlands.

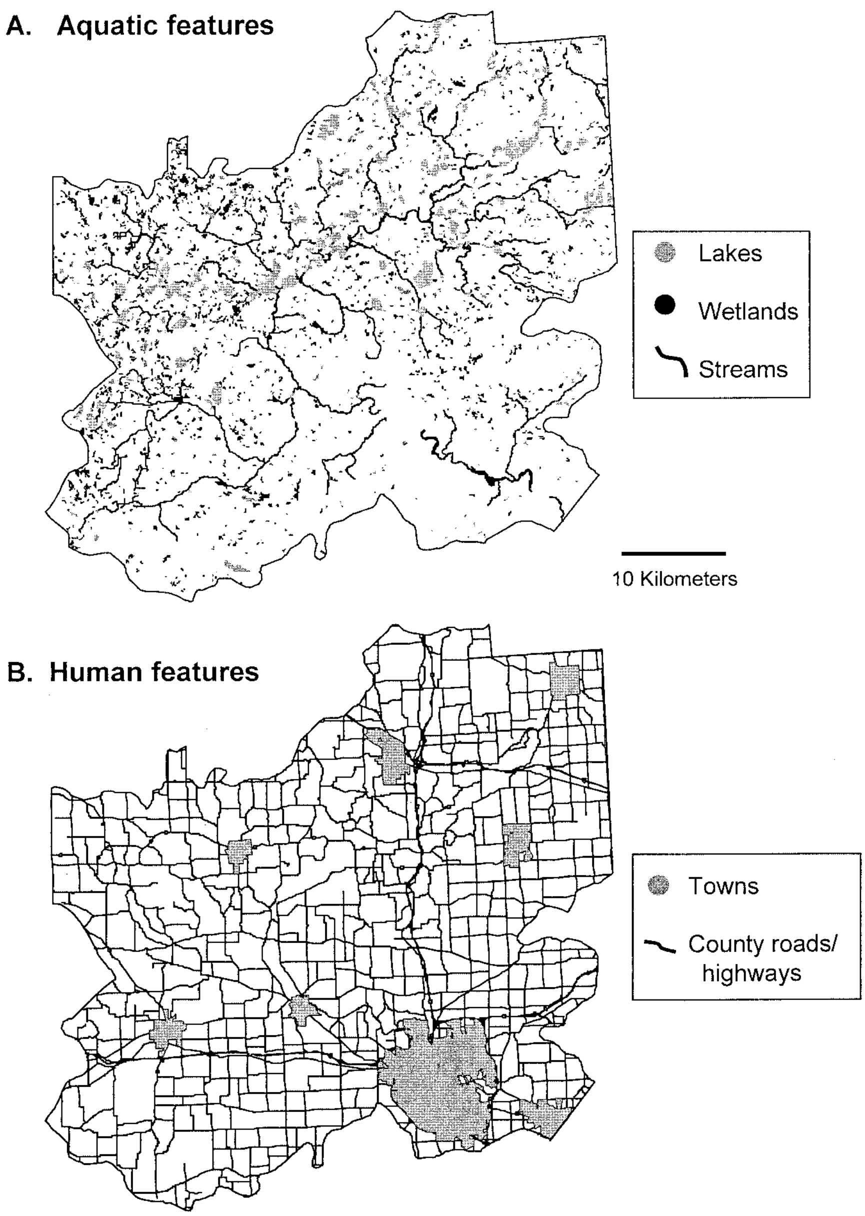

Figure 2. The location and spatial arrangement of aquatic (**A**) and human (**B**) landscape features in the study area. Note there are a total of nine towns, one of which is too small to appear in the figure.

ing out to 1000 m from the lake shoreline. Each parcel of land within the buffers was assigned to a buffer of the nearest lake. Land use/cover proportions were then calculated for each buffer distance around each lake. We then calculated a mean buffer land use/cover proportion for each buffer distance by calculating an area-weighted mean around all lakes. The number of values that went into each area-weighted mean varied across landscape features and buffer distances. The sample size for each mean is presented in Table 2. We calculated the variance around each mean using an estimate of variance for ratio data (Cochran 1953, Lockwood and others 1999). Land use/cover proportions were then calculated for the entire study site (excluding towns and public lands), which we define as the overall "regional" land use/cover proportion. In addition, to determine what proportion of the total study area was represented for each buffer distance, we calculated the proportion of the study area that was included in each buffer distance.

To quantify the distribution of land use/cover around different landscape features, the proportion of land use/cover in each buffer distance class was plotted against the distance to the landscape feature as de-

Table 1. Summary characteristics of aquatic ecosystems and human made landscape features

		Area or length			
	Number	Total	Range	Mean	Median
Lakes	453	6249 ha	1–412 ha	13.8 ha	3.4 ha
Wetlands	1296	5455 ha	1–77 ha	4.2 ha	2.4 ha
Streams	110 segments	553 km	0.6–24.7 km	5.0 km	4.0 km
Country roads/highways	1322 segments	2466 km	0.1–12.0 km	1.9 km	1.5 km
Towns	9	1163 ha	4–710 ha	129.3 ha	65.4 ha

scribed in the general case in Figure 3. Each data point on the graphs in Figure 3 represents the area-weighted mean for one buffer distance around the landscape feature. The buffer distances are not cumulative and include only the 100 m beyond the previous buffer. For example, the 200-m buffer includes the land between 100 and 200 m away from a landscape feature. Although there is likely to be some spatial autocorrelation in the ten buffers, because each buffer is compared to the regional proportion and not to other buffers, our statistical tests should not be biased.

The shape of the plot or the land use/cover proportion within each buffer and its relationship to the overall regional land use/cover proportion, as shown in Figure 3, defines our measure of land use/cover distribution. We inferred that the land use/cover was positively associated (Figure 3A) or negatively (Figure 3B) associated with a landscape feature if the proportion of land use/cover in a buffer was higher or lower, respectively, than the regional proportion. If the land use/cover proportion in a buffer was not different than the regional proportion, we inferred that there was no association with the landscape feature (Figure 3C). This last case was our null hypothesis—that there is no association between land use/cover and the landscape feature in any of the ten buffers, and thus the proportion of land use/cover within buffers is roughly equal to the regional land use/cover proportion. These trends do not identify a causal relationship, only an association.

To determine if the association between a landscape feature and land use/cover was significant, we compared the weighted mean land use/cover proportion for each buffer distance class to the regional proportion using a t test for comparisons to a known value (i.e., the regional land use/cover proportion) (Sokal and Rohlf 1995). The t tests determined the spatial extent of the influence of each landscape feature by quantifying the distance from the landscape feature that was significantly different from the regional proportion. We did not adjust our significance level for multiple comparison tests (i.e., Bonferroni corrections) even though we were conducting many individual t tests, in part because the comparisons we were making were planned prior to collecting our data (Stewart-Oaten 1995) and because we were more interested in the overall shape of the plots (as in Figure 3), rather than the specific significance level at each buffer distance. Finally, we also summarized the results by summing the number of significant t tests for each land use/cover feature combination and calculated the percentage of buffers that were significant to determine whether the presence of aquatic ecosystems influenced the spatial distribution of land use/cover to a similar degree as human features.

Results

Land use/cover change in the entire study area (including public lands and towns) has shown patterns consistent with other studies conducted in the Midwest United States (Medley and others 1995, Kleiman and Erickson 1996). Urban land use/cover has increased (5% to 25% from 1938 to 1995) at the expense of agricultural land use (decreased from 56% to 28%); forested land use/cover has actually increased slightly (from 15% to 18%); and wetland area has decreased (from 10% to 7%) over the 57-year time period. The remaining two types of land use/cover include nonforested vegetation (includes areas classified as grassland and shrubland) and surface water (lakes and streams), which comprised 17% and 4% of the area in 1995, respectively.

The proportion of the study area that is represented by each of the buffer distances around each aquatic and human feature differ based on the different distribution of features across the landscape and the different shape of each feature (Figure 4). We have removed the effect of different buffer areas by analyzing proportions and by calculating weighted means based on buffer area. The total area within a given buffer distance varies from 1% to 22% of the study area (Figure 4). Therefore, each individual buffer distance (noncumulative distance) is a relatively small subset of the entire study area. Also relevant to interpreting our results is the

Table 2. *t* tests of buffer proportions versus regional proportion[a]

Land use/cover	Distance (m)	Aquatic ecosystems									Human features						% of buffers significant	
		Lake			Wetland			Stream			Road			Town				
		P	*d*	(*N*)	*P*	*d*	(*N*)	*P*	*d*	(*N*)	*P*	*d*	(*N*)	*P*	*d*	(*N*)	Aquatic	Human
1995																		
Residential	100	0.001	+	(439)	0.001	−	(1280)	0.01	−	(103)	0.001	+	(1210)	0.001	+	(9)	73	55
	200	0.001	+	(444)	0.001	−	(1275)	0.05	+	(104)			(1172)	0.02	+	(9)		
	300	0.001	+	(444)	0.001	−	(1262)	0.01	+	(104)	0.001	−	(1128)	0.05	+	(9)		
	400	0.001	+	(445)			(1213)	0.05	+	(103)	0.001	−	(1066)			(9)		
	500	0.001	+	(442)			(1155)	0.05	+	(102)	0.001	−	(1008)			(9)		
	600	0.001	+	(438)			(1067)	0.02	+	(100)	0.001	−	(922)			(9)		
	700	0.01	+	(428)			(977)	0.02	+	(101)	0.001	−	(831)			(9)		
	800	0.05	+	(414)	0.001	+	(863)	0.05	+	(100)	0.001	−	(677)			(9)		
	900			(398)	0.001	+	(738)			(100)	0.01	−	(413)			(9)		
	1000			(375)	0.001	+	(619)			(99)			(246)			(9)		
Agriculture	100	0.001	−	(439)	0.001	+	(1280)	0.001	−	(103)			(1210)	0.001	−	(9)	53	35
	200	0.001	−	(444)	0.001	+	(1275)	0.01	−	(104)	0.001	+	(1172)			(9)		
	300	0.001	−	(444)	0.001	+	(1262)	0.05	−	(104)	0.01	+	(1128)			(9)		
	400	0.001	−	(445)	0.01	+	(1213)	0.05	−	(103)			(1066)			(9)		
	500	0.001	−	(442)			(1155)			(102)			(1008)			(9)		
	600	0.001	−	(438)			(1067)			(100)			(922)			(9)		
	700	0.02	−	(428)			(977)	0.05	−	(101)	0.001	−	(831)			(9)		
	800			(414)			(863)			(100)	0.001	−	(677)			(9)		
	900			(398)			(738)			(100)	0.001	−	(413)			(9)		
	1000			(375)			(619)			(99)	0.001	−	(246)			(9)		
Forest	100	0.001	+	(439)	0.001	+	(1280)	0.001	+	(103)	0.001	−	(1210)	0.001	−	(9)	43	60
	200	0.001	+	(444)	0.001	+	(1275)			(104)	0.001	−	(1172)	0.01	−	(9)		
	300	0.001	+	(444)	0.01	+	(1262)			(104)			(1128)			(9)		
	400	0.001	+	(445)			(1213)			(103)	0.001	+	(1066)			(9)		
	500	0.001	+	(442)			(1155)			(102)	0.001	+	(1008)			(9)		
	600	0.01	+	(438)			(1067)			(100)	0.001	+	(922)			(9)		
	700	0.05	+	(428)			(977)			(101)	0.001	+	(831)			(9)		
	800			(414)			(863)			(100)	0.001	+	(677)			(9)		
	900			(398)			(738)			(100)	0.001	+	(413)			(9)		
	1000	0.01	+	(375)			(619)	0.05	+	(99)	0.001	+	(246)	0.05	−	(9)		
1938																		
Residential	100	0.001	+	(439)	0.001	−	(1280)	0.001	−	(103)	0.001	+	(1210)	0.001	+	(9)	20	50
	200	0.02	+	(444)			(1275)			(104)	0.001	−	(1172)	0.05	+	(9)		
	300			(444)			(1262)			(104)	0.001	−	(1128)			(9)		
	400			(445)			(1213)			(103)	0.001	−	(1066)			(9)		
	500	0.01	−	(442)			(1155)			(102)	0.001	−	(1008)			(9)		
	600			(438)			(1067)			(100)	0.001	−	(922)			(9)		
	700			(428)			(977)			(101)	0.001	−	(831)			(9)		
	800			(414)			(863)			(100)	0.001	−	(677)			(9)		
	900			(398)			(738)			(100)			(413)			(9)		
	1000	0.001	−	(375)			(619)			(99)			(246)			(9)		
Agriculture	100	0.001	−	(439)			(1280)	0.001	−	(103)	0.001	+	(1210)	0.02	+	(9)	30	65
	200	0.001	−	(444)	0.001	+	(1275)	0.01	−	(104)	0.001	+	(1172)	0.01	+	(9)		
	300	0.001	−	(444)	0.01	+	(1262)			(104)	0.001	+	(1128)	0.05	+	(9)		
	400	0.001	−	(445)			(1213)			(103)			(1066)	0.05	+	(9)		
	500	0.05	−	(442)			(1155)			(102)	0.001	−	(1008)			(9)		
	600			(438)			(1067)			(100)	0.001	−	(922)			(9)		
	700			(428)			(977)			(101)	0.001	−	(831)			(9)		
	800			(414)			(863)			(100)	0.001	−	(677)			(9)		
	900			(398)			(738)			(100)	0.001	−	(413)			(9)		
	1000			(375)			(619)			(99)	0.001	−	(246)			(9)		
Forest	100	0.001	+	(439)	0.01	+	(1280)	0.001	+	(103)	0.001	−	(1210)	0.001	−	(9)	37	85
	200	0.001	+	(444)	0.02	+	(1275)			(104)	0.001	−	(1172)	0.02	−	(9)		
	300	0.001	+	(444)			(1262)			(104)	0.001	−	(1128)	0.05	−	(9)		
	400	0.01	+	(445)			(1213)			(103)	0.001	+	(1066)	0.005	−	(9)		
	500	0.05	+	(442)			(1155)			(102)	0.001	+	(1008)	0.005	−	(9)		
	600			(438)			(1067)			(100)	0.001	+	(922)	0.005	−	(9)		
	700			(428)			(977)			(101)	0.001	+	(831)			(9)		
	800			(414)			(863)			(100)	0.001	+	(677)			(9)		
	900			(398)			(738)	0.05	+	(100)	0.001	+	(413)			(9)		
	1000	0.05	+	(375)			(619)	0.005	+	(99)	0.001	+	(246)	0.05	−	(9)		

[a] *P* is the *P* value for the individual *t* tests, *d* is the direction of the association ('+' is a positive association, and '−' is a negative association), (*N*) is the number of individual features in each buffer analysis, and "% of buffers significant" is the percent of the buffers around a given landscape feature that are significantly different from the regional proportion.

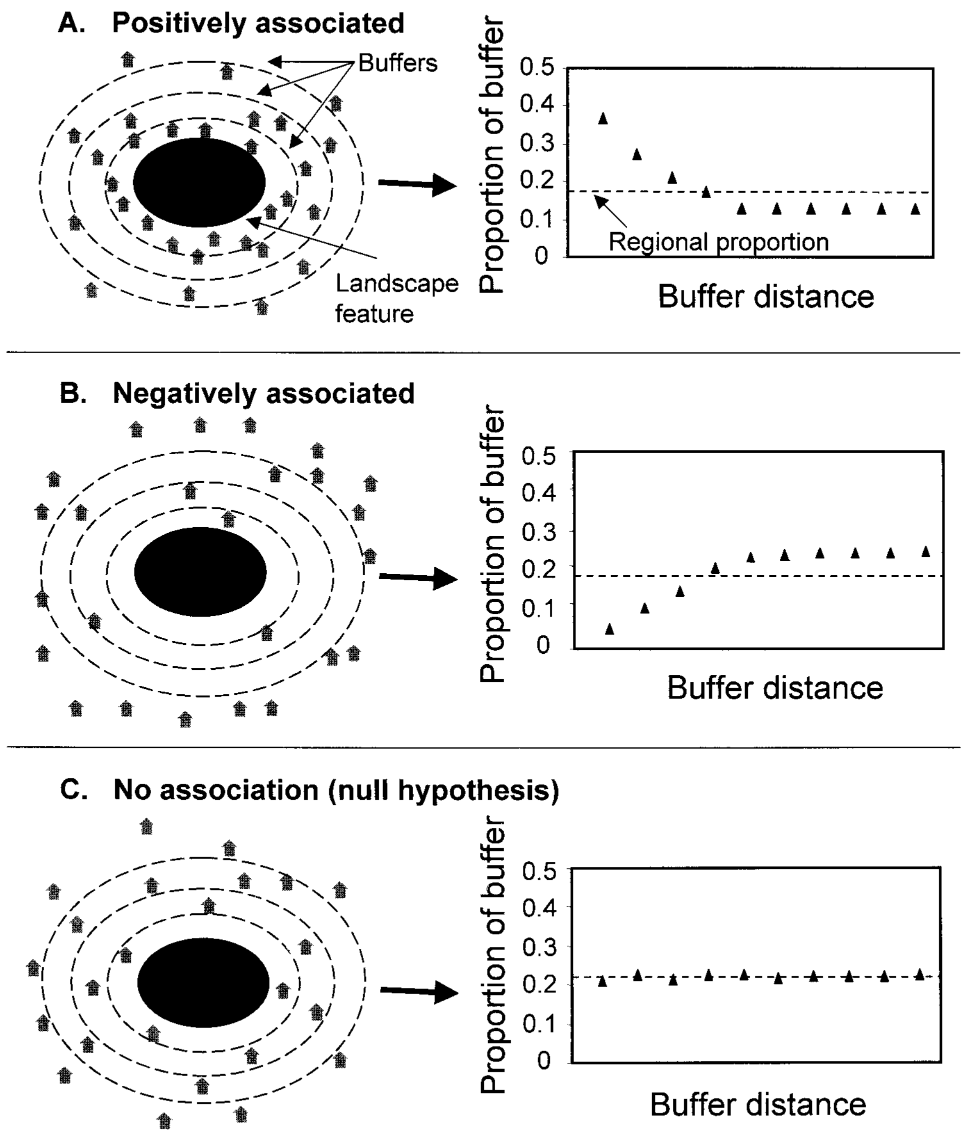

Figure 3. Diagram showing how the distribution of land use/cover around each landscape feature was quantified. The black ovals represent a landscape feature (e.g., a lake or town). The symbols surrounding each feature represent an individual land use type (e.g., residential land use/cover). The concentric circles represent the 100-m buffers surrounding the feature (note, only three buffers are shown for each diagram). The data plotted to the right of each diagram are the weighted mean proportion of land use/cover within each buffer distance class against the buffer distance (data for ten buffer distance classes are plotted). The dashed line is the proportion of land use/cover within the entire region of the study area. When a land use/cover type is distributed more densely around a landscape feature compared to the regional proportion, then we infer that the land use/cover is positively associated with that landscape feature (**A**). When a land use/cover type is distributed less densely around a landscape feature compared to the regional proportion, then we infer that the land use/cover is negatively associated with that landscape feature (**B**). Finally, when a land use/cover type is distributed similarly around a landscape feature compared to the regional proportion, then we infer that the land use/cover is not associated with that landscape feature (**C**).

cumulative percent area of the ten buffers for each landscape feature. For example, for lakes, wetlands, and streams, the ten concentric 100 m buffers include 52%, 80%, and 49% (respectively) of the entire study area, whereas the ten buffers for towns and roads include 10% and 97% (respectively) of the study area. This means, for example, that almost any parcel of land in the study area is within 1000 m of a road, but that

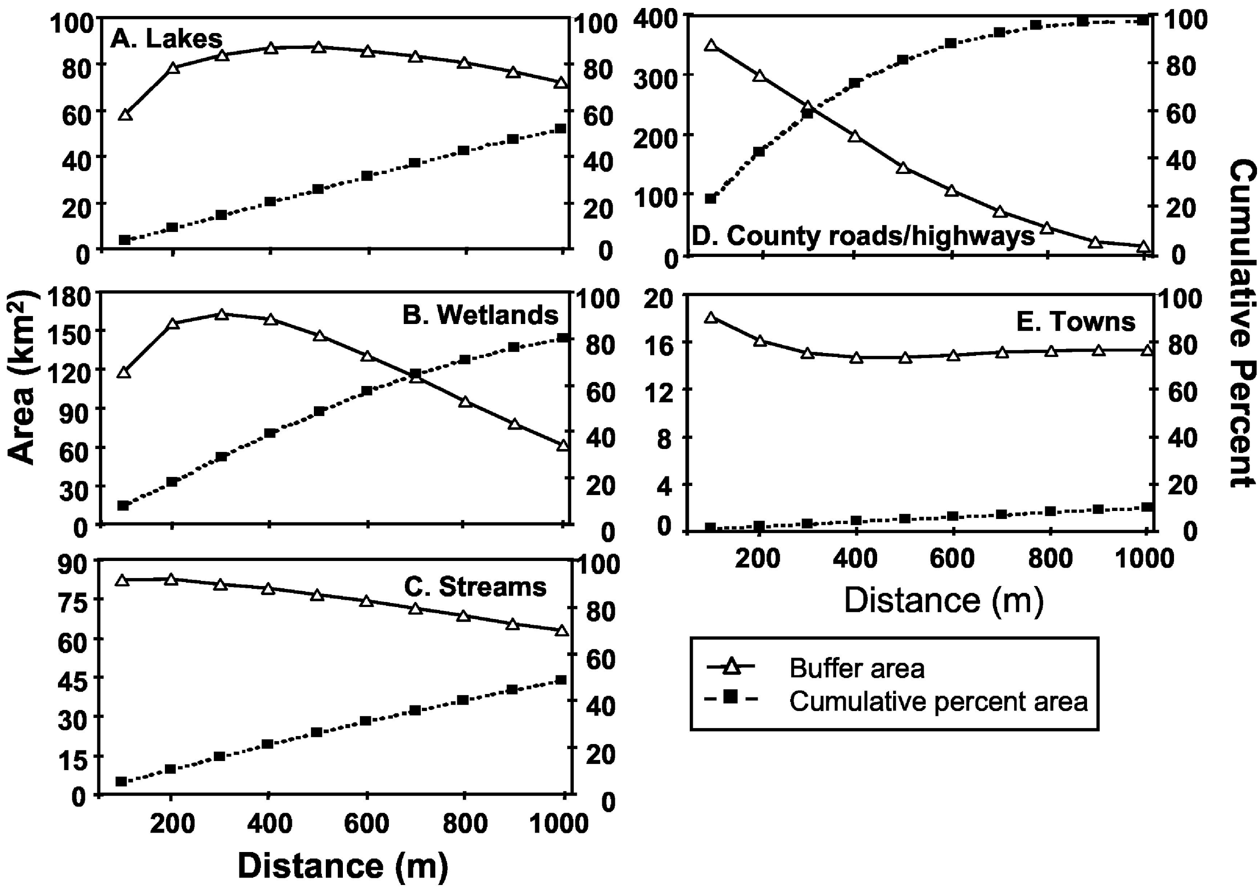

Figure 4. The area of land within each buffer distance class (triangles) and the cumulative percent area in each buffer distance class (squares) for each landscape feature.

only 10% of the land in the study area is within 1000 m of a town.

Effects of Individual Landscape Features on Land Use/Cover

Both aquatic (lakes, wetlands, and streams) and human (county roads/highways and towns) landscape features were strongly associated with the distribution of land use/cover in our study site, although the magnitude and direction of the relationships between each feature and land use/cover type differed. Below we explore the specific relationships between both aquatic and human features and three land use/cover types for both time periods.

Residential land use/cover. We found strong relationships between each aquatic ecosystem and human landscape feature and residential land use/cover in 1995. We were not surprised that one of the stronger relationships was between lakes and riparian (within 100 m) residential cover (Figure 5A). However, it was surprising that residential cover was positively associated around lakes up to 800 m away—a distance well beyond the riparian zone (Table 2, 1995). Residential cover around lakes follows distribution A in our conceptual model (Figure 3A) that shows a positive association between the landscape feature and land cover proportion, which decreases with distance from the feature. Residential land use/cover around wetlands and streams shows a negative association (Figure 5B,C), but with a slight modification of distribution B in our conceptual model (Figure 3B). Residential land use/cover within 300 m of wetlands was negatively associated with the landscape feature, whereas only the first 100-m buffer was negatively associated with streams, beyond which, residential land use/cover was significantly higher than the regional proportion out to the 800 m buffer. Residential land use/cover around both county roads/highways and towns showed similar trends to lakes, with some minor differences (Figure 5D,E). For county roads/highways, the positive association of residential land use/cover is only significant in the first 100 m buffer. Thus, although the type of

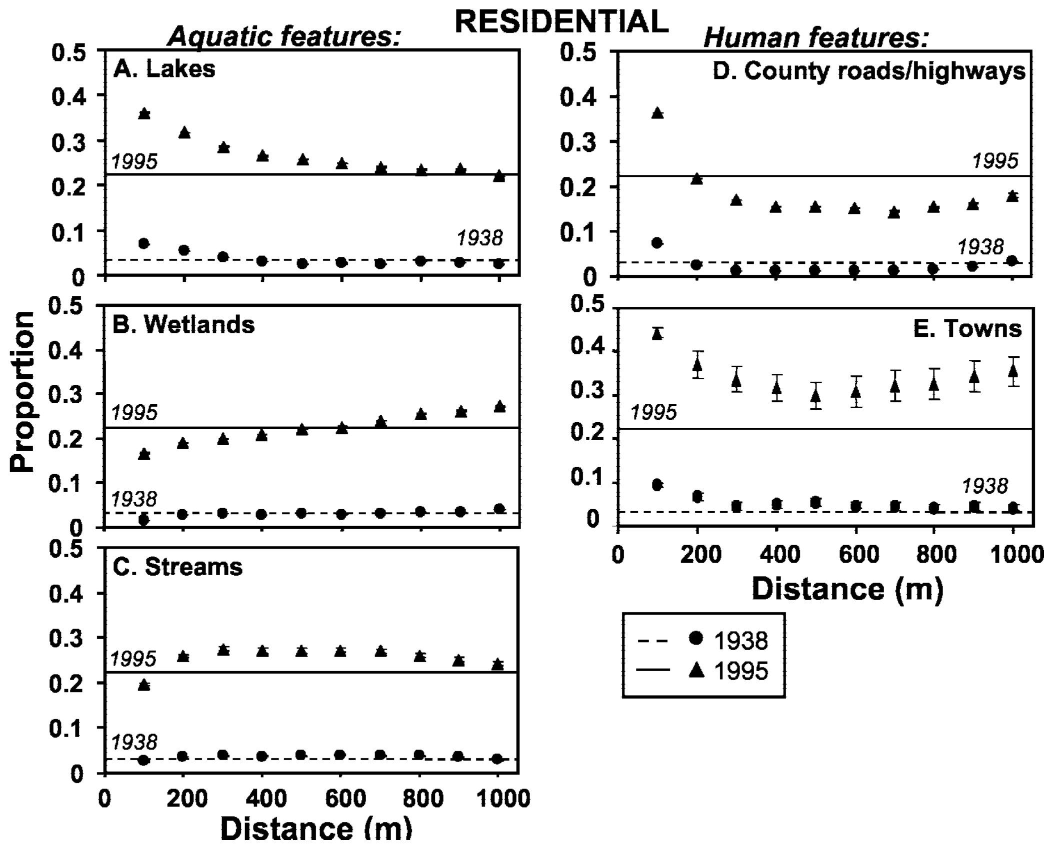

Figure 5. Weighted means and 95% confidence intervals of the proportion of residential land use/cover in 1938 (circles) and 1995 (triangles) for each buffer distance around lakes (**A**), wetlands (**B**), streams (**C**), county roads/highways (**D**), and towns (**E**). Dashed lines are the regional proportions of residential land use/cover in 1938; solid lines are the regional proportions of residential land use/cover in 1995. Note the confidence intervals are almost always smaller than the symbol itself.

association between residential land and both county roads/highways and lakes were similar, the distance of influence for lakes was stronger for lakes in that it extended to 800 m, whereas the effect of county roads/highways extended only to 100 m. Around towns, all of the buffers had higher proportions of residential land use/cover compared to the regional proportion, however only the first three buffers were significant.

In 1938, although the distribution of residential land use/cover around both aquatic and human features was similar to 1995 for most cases, the relationships were weaker in 1938 than in 1995 (Figure 5, Table 2). For lakes, only the first two buffer distances had significantly higher residential land use/cover than the regional proportion in 1938. For wetlands and streams, only the first buffer had significantly less residential land use/cover in 1938, similar to 1995. For county roads/highways and towns, the first buffer distances were similar to 1995 in that they were positive and significant, but with lower magnitude of difference between the buffer and the regional proportions.

Agricultural land use/cover. Agricultural land use/cover in 1995 was negatively associated with lakes and streams, but was slightly positively associated with wetlands (Figure 6A–C). For both lakes and streams, the proportion of agricultural land use/cover was most different from the regional proportion in the nearest buffer (100 m), and steadily increased to the regional proportion beyond 400 m (Figure 6A,B). For wetlands, the proportion of agricultural land use/cover in the nearest four buffers was slightly higher than the regional proportion (Figure 6C). Near county roads/highways, agricultural land use/cover was similar to the regional proportion (Figure 6D). For towns, although all buffers contained lower proportions of agricultural land use/cover than the regional proportion, only the first buffer was significant (Figure 6E).

The results for agricultural land use/cover in 1938 were similar to 1995 except for a few key differences (Figure 6). First, for aquatic ecosystems, although the trends were similar, the number of significant buffers in 1938 was lower than in 1995 (Table 2). Second, agri-

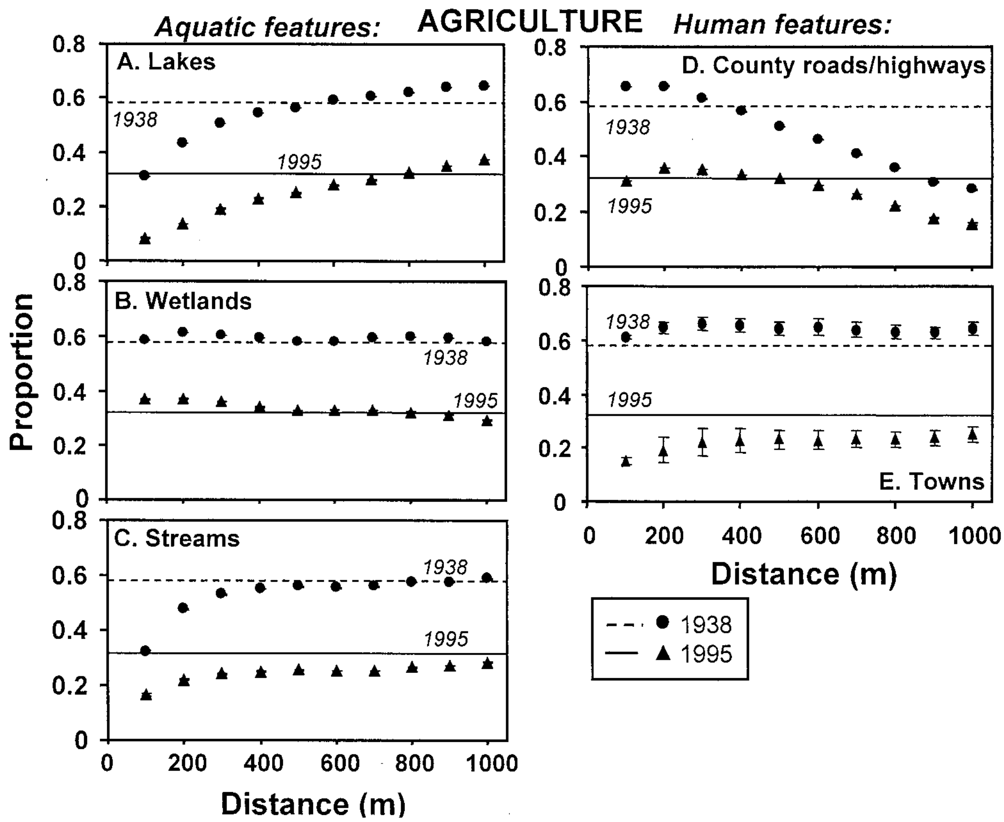

Figure 6. Weighted means and 95% confidence intervals of the proportion of agricultural land use/cover in 1938 (circles) and 1995 (triangles) for each buffer distance around lakes (**A**), wetlands (**B**), streams (**C**), county roads/highways (**D**), and towns (**E**). Dashed lines are the regional proportions of agricultural land use/cover in 1938; solid lines are the regional proportions of agricultural land use/cover in 1995. Note the confidence intervals are almost always smaller than the symbol itself.

cultural land around county roads/highways was similarly distributed in 1938 and 1995. However, the first buffer was significantly positive in 1995 but not in 1938. Finally, for towns, agricultural land use/cover in buffers around towns was higher than the regional proportion in 1938, but lower in 1995.

Forested land use/cover. Forested land use/cover in 1995 was positively associated with the location of all aquatic ecosystems (Figure 7A–C). For wetlands and streams, the proportion of forested land use/cover steadily decreased with buffer distance and was significantly different than the regional proportion to 300 m and 100 m respectively (Table 2A). However, for lakes, the proportion of forest immediately surrounding lake shorelines was lower than the 200 or 300 m buffers, and the number of significant buffers extended to 700 m. Forested land use/cover proportions around county roads/highways and towns were generally lower than the regional proportion up to about 200 m (Figure 7D,E).

The results for forested land use/cover in 1938 were similar to results in 1995, and compared to residential and agricultural land use/cover showed less change around all landscape features. However, the number of significant buffers for aquatic ecosystems was lower in 1938 compared to 1995 and was higher for human features in 1938. In addition, forested land use/cover increased in all areas of the region from 1938 to 1995 except for areas within 100 m of lakes, which suggests that today, forested land along lake shorelines is more likely to have forest converted to other land use/cover types than elsewhere in the rest of the region. For wetlands, there was less forested land surrounding them in 1938 compared to 1995. In summary, there was more forested land within 1000 m of aquatic ecosystems in 1995 compared to 1938, except within 100 m of lakes.

Comparisons of Aquatic and Human Landscape Features

To compare overall results between aquatic and human features we summed the number of buffers that

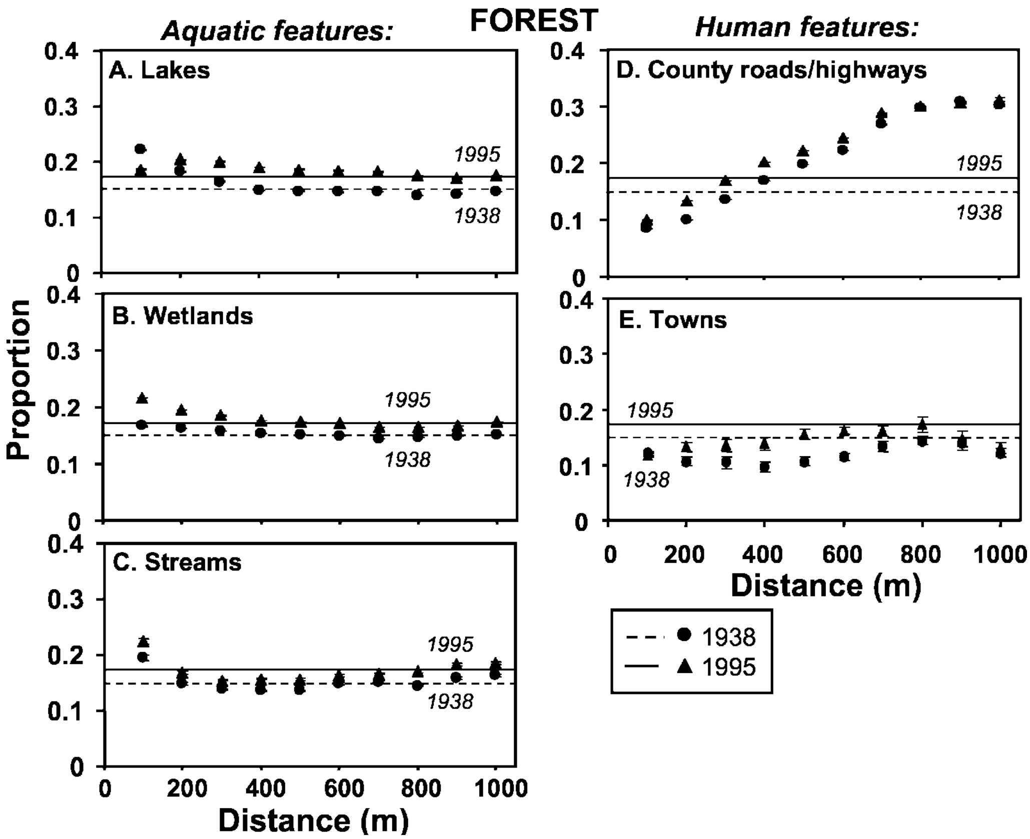

Figure 7. Weighted means and 95% confidence intervals of the proportion of forested land use/cover in 1938 (circles) and 1995 (triangles) for each buffer distance around lakes (**A**), wetlands (**B**), streams (**C**), county roads/highways (**D**), and towns (**E**). Dashed lines are the regional proportions of forested land use/cover in 1938; solid lines are the regional proportions of forested land use/cover in 1995. Note the confidence intervals are almost always smaller than the symbol itself.

were significantly different from the watershed proportion for each time period. In 1938, 28% of the buffers were significant around aquatic ecosystems and 66% for human features. The balance switched in 1995 to 57% of buffers significant around aquatic ecosystems and 50% of the buffers around human features, suggesting a trend towards a greater influence of aquatic ecosystems on land use/cover distribution. Specifically, for both residential and agricultural land use/cover, the influence of aquatic ecosystems on land use/cover distribution increased from a relatively low percentage of significant buffers in 1938 to a much higher percentage in 1995 (Table 2). On the other hand, the influence of human landscape features on residential land use/cover stayed about the same across the two time periods and decreased for agricultural land use/cover. For forested land use/cover, there was a higher percentage of significant buffers for human features in 1938 than for aquatic features. By 1995, however, the percent of significant buffers decreased for human features and increased for aquatic features.

Our conceptual model of the association between aquatic ecosystems (and human features) and land use/cover defines three different land use/cover distributions: positive, negative, or no association (Figure 3). Our results show that each aquatic ecosystem has unique relationships to land use/cover and fits within each of these possible models (Table 3). In general, lakes attract residential development as well as forest near their shorelines, to the exclusion of agricultural land. However, for wetlands and streams, the relationships to land use/cover distributions are quite different than for lakes. Wetlands and streams are negatively associated with residential and agricultural lands but are positively associated with forested lands. In contrast, for human features, we found that county roads, highways, and towns generally attracted residential and agricultural land use, to the exclusion of forested land. Although these general patterns were not equally strong through time, there was some consistency in the patterns in 1938 and in 1995.

Table 3. Generalized associations of each landscape feature type in 1938 (first letter) and 1995 (second letter) to each land use/cover type[a]

	Aquatic features			Human features	
Landscape feature	Lakes	Wetlands	Streams	County roads/hwys	Towns
Residential	A/A	C/B	C/B	A/A	A/A
Agriculture	B/B	C/A	B/B	A/C	A/B
Forest	A/A	A/A	A/A	B/B	B/B

[a]A is a positive association, B is a negative association, and C is no association. See Figure 3 for further description of the associations.

Discussion

To incorporate aquatic ecosystems into land use research, planning, and management, it will be necessary to take the unique perspective that examines how aquatic ecosystems influence human activities, rather than only the reverse. Our results suggest that this perspective is important in regions near aquatic ecosystems, and we make four important conclusions. First, aquatic ecosystems can influence the fine-scale distribution of residential, agricultural, and forested land use/cover to a similar degree as known human drivers of land use/cover (e.g., distance to towns and county roads/highways). Second, the effect of aquatic ecosystems appears to extend well beyond the 100-m riparian zone. Third, the influence of aquatic ecosystems on land use/cover distribution strongly depends on the ecosystem type; thus, lakes, streams, and wetlands must be considered separately. Fourth, the strength of the association between aquatic ecosystems and land use/cover increased from 1938 to 1995, although the overall patterns were similar. Although there are many additional factors that are likely to be associated with the distribution of land use/cover that were not part of our study, our results show that aquatic ecosystems can explain some of the variability in land use/cover distributions across the landscape, and their role in landscape change warrants further research.

Quantifying these spatial associations has rarely been done and is an important first step in explicitly linking aquatic ecosystems to land use change (Riera and others 2001, Schnaiberg and others 2002). The strength of our study lies in the general patterns that we observed, the comparisons across different aquatic ecosystem types, and the comparisons to known human drivers of land use. For example, it is well known that the location of towns and roads influences the distribution of residential development and land use/cover in general (Burgess 1967). The success of our methods in detecting these known relationships around human landscape features suggests that the distributions we observed around lakes, wetlands, and streams are also real and that aquatic ecosystems are associated with land use/cover distributions. In addition, our conceptual model defining three different distributions of land use/cover around landscape features provides a means for comparisons across different landscape features (aquatic versus human).

Relationships Between Aquatic Ecosystems and Land Use/Cover Distributions

Our empirical approach complements existing sociological, economic, and historical research on the valuation of aquatic ecosystems and supports some of the conclusions made about the increased value and use of land around lakes (David 1968, Lansford and Jones 1995, Siderelis and Perrygo 1996, Riera and others 2001), wetlands (Doss and Taft 1996, Mahan and others 2000), and streams (Kulshreshtha and Gillies 1993). However, our study is one of the first to actually quantify how these human values translate into the distribution of land use/cover on the landscape. We found that lakes, streams, and wetlands each have very different relationships to land use/cover distribution, and we explore each in detail below.

Not surprisingly, we found that lakes were strongly positively associated with residential land use/cover and negatively associated with agricultural land use/cover in 1995. The relationship with agricultural land use/cover may be due to the higher concentration of residential land use/cover near lakes, which raises property values and drives out farmers (Medley and others 1995). Schnaiberg and others (2002) also found that 60% of the buildings in a rural/recreation-dominated county in northern Wisconsin were located within 100 m of a lake. In our study site, we found approximately 20% of the total residential development occurred within 100 m of a lake. Although our value is lower than the Wisconsin study, which may be due to the fact that our study site is more urbanized and agricultural than the Wisconsin study site, the number is still large. Others have found that lakefront property is more highly valued than nonlakefront property (David 1968, Lansford and Jones 1995, Siderelis and Perrygo 1996). However, we found that the positive association between residential land use/cover and lakes extended beyond 100 m, out to 800 m. In fact, we found that 40% of the residential development of the study site can be found within 800 m of a lake. The fact that we found that residential development extended beyond 100 m from lakes is interesting because many of the attributes associated with lakefront property are assumed to be absent beyond 100 m. Our results suggest that to focus solely on riparian areas around aquatic ecosystems (within 100 m of shorelines) may not be sufficient to explain their importance in influencing land use change.

For streams, we also found a positive association with residential land use/cover at a distance of 100–800 m in 1995. This result supports research that shows that even a view of a river will add value to land for residential use (Kulshreshtha and Gillies 1993). However, the area within 100 m of streams had a positive association with forested land cover, coupled with a negative association of residential land use/cover. This result may be explained by efforts to preserve natural vegetation in the riparian zones of streams that have occurred in the United States (Bollens 1990, Kleiman and Erickson 1996). This conservation of stream riparian zones is supported by studies on the attitudes of some rural residents towards riparian landscapes that have found that many residents prefer the image of vegetation near rivers (Ryan 1998).

Although many of the associations for wetlands and streams are similar (Table 3), there are some key differences that are likely due to the complicated attitudes people have towards wetlands. Our finding that agricultural land use/cover is positively associated with wetlands appears to support previous research showing that, historically, wetlands were drained for agriculture in Michigan (Prince 1997). However, the negative association of residential development around wetlands was surprising because it is in contrast to studies showing a preference of people to live near depressional wetlands (Doss and Taft 1996). Similarly, Mahan and others (2000) found that both increasing the size of the nearest wetland to residential property or decreasing the distance by 1000 ft increased the value of the home. Our results contradict these studies and may be the result of wetland protection policies in place now, the potentially high likelihood of flooding near wetlands, or other factors, but we cannot be sure.

Although human attitudes towards aquatic ecosystems have changed through time (Zedler and others 1998), we did not detect large changes in the land use/cover distributions between 1938 and 1995 (Table 3). However, both the magnitude and the extent of the association of each land use/cover type with human and aquatic landscape features changed from 1938 to 1995. For example, around all aquatic ecosystems, it appears that there were either weak or no associations with each land use/cover in 1938, with both more and stronger associations observed in 1995. Interestingly, the relative effects of aquatic and human drivers changed through time. Overall, in 1938, human features were more often associated with the distribution of land use/cover than aquatic ecosystems (67% of buffers around human features were significant versus 29% around aquatic features), but in 1995, the relative importance reversed and the two types of features were more even (50% of buffers around human features were significant versus 56% around aquatic features) (Table 2). Thus, currently, land use/cover distribution in this region appears to be more associated with aquatic landscape features than human features. This result suggests that it will be important to explicitly consider the effect of aquatic systems on the spatial arrangement of future land use in this region.

Implications

Our research has important implications for understanding future changes in water quality. In this region of Michigan, the general projected land use trends are conversions from agricultural land to residential development, with slight increases in forested land as a result of abandonment of less suitable agricultural land (Erickson 1995). If the current land use/cover distributional trends observed from 1938 through 1995 continue along the same trajectories, then there will be likely elimination of forested riparian areas around lakes, as well as increased urbanization pressure beyond 100 m of streams. These trends are likely to lead to future water quality changes in both streams and lakes. For example, the loss of riparian forested land use/cover around lakes will likely limit the use of vegetated riparian buffer areas to decrease nutrient flow into lakes (Osborne and Kovacic 1993). It may be important to put more emphasis into developing stricter zoning and building ordinances around lake shorelines that limit development or find ways to increase the amount of lakeside vegetation. For streams, efforts have been put into place to preserve stream riparian and floodplain areas (i.e., forested riparian buffer zones) across the country (Bollens 1990) and specifically in southeast Michigan (Kleiman and Erickson 1996). However, beyond 100 m away from streams, residential land use/cover is elevated, suggesting that present conservation efforts may not extend beyond the riparian zone. Finally, although wetlands do not appear to be subject to development pressure, forested and agricultural land is elevated around wetlands and current land use trends in this area are to convert agricultural land to residential development. If this agricultural land is converted, there may be increasing pressure on developing these sensitive areas around wetlands, especially since these areas are highly valued for residential landowners (Doss and Taft 1996). Additionally, because we did not include in our analysis wetlands that were converted to agriculture or residential land use/covers between 1938 and 1995 (e.g., the wetlands that have been lost since 1938), we may have underestimated the effect of development on wetlands and overestimated the conservation of forest around wetlands. For all of these aquatic ecosystems riparian zones play a proportionally greater role in influencing water quality than other parts of the watershed, but they cannot be expected to mitigate the effects of uncontrolled modification of the landscape, especially when riparian zones and areas immediately beyond them are also under intense development pressure.

We have provided evidence for our empirical approach to study the relationship between landscape features and land use/cover and suggest that, eventually, sociological, economic, historical, modeling, and empirical approaches should be combined to acquire a more complete understanding of people's values and uses of the landscape. Our results may be typical for north temperate glaciated landscapes in regions with a relatively large and growing human population. However, our results are likely to have implications for other regions as well because some human attitudes and subsequent actions towards aquatic ecosystems may be universal. A complete understanding of how natural features, including aquatic ecosystems, affect land use/cover distribution will add to our ability to predict land use change in the future and should help to better manage land use in environmentally sensitive and highly valued areas such as riparian zones. A thorough understanding of the mechanisms behind the observed land use/cover distributions in our study site was beyond the scope of this research. However, it is likely that legislative, social, and economic factors interact to change both human attitudes and behavior towards lakes, wetlands, and streams and thus their relationships with the distribution of land use/cover.

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