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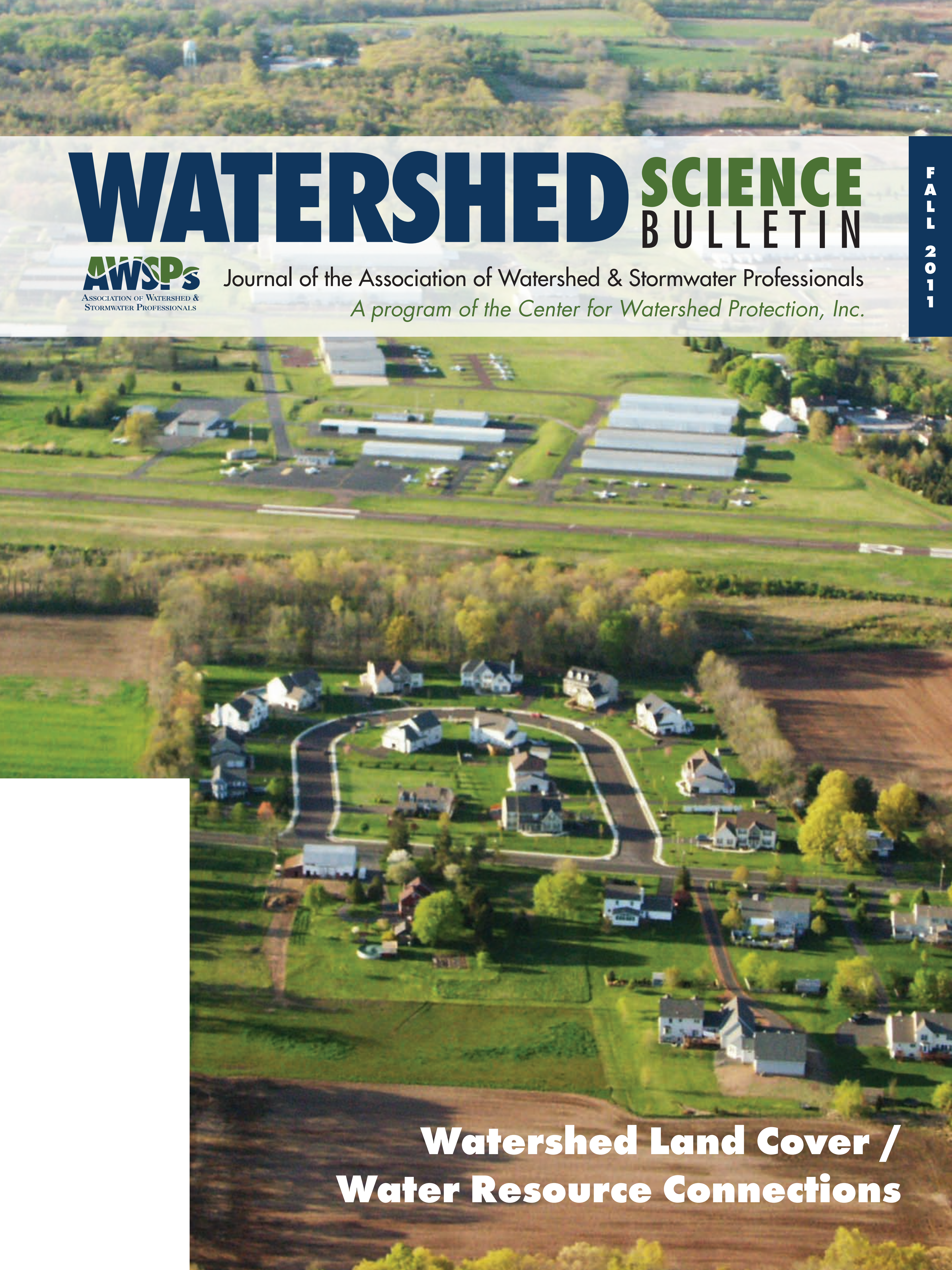

Watershed Land Cover / Water Resource Connections

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Cover photo courtesy of Dot Cappiella
This bird's-eye view of Bucks County, Pennsylvania, taken from a hot air balloon, shows the variety of land cover types on this rural and suburban landscape. Trees, turf, pavement, cropland, and even bare soil are present in this fast-developing suburb of Philadelphia.

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Land Cover Change in the Riparian Corridors of Connecticut

Emily H. Wilson,[a*] Juliana Barrett,[b] and Chester L. Arnold[c]

Abstract

Riparian, or streamside, corridors are environmentally important areas critical to shoreline stability, pollutant removal, and both aquatic and terrestrial wildlife habitat. The University of Connecticut's Center for Land Use Education and Research recently conducted a statewide study of land cover change in riparian zones in Connecticut in an attempt to (1) characterize change in these areas and compare it to overall land cover change, (2) gain insight into what factors drive this change, and (3) determine priority areas for outreach to local land use decision makers. The amount of developed land, and increases in developed land during the study period (1985–2006), were lower in the riparian corridors than in the state as a whole. However, increases in riparian zone development within any particular town were closely correlated with overall increases in development in that town. These results suggest that overall development pressure is the primary driver of new development in riparian areas, though the effects of this pressure are mitigated to some extent by local zoning codes related to building suitability and by wetlands and watercourses regulations related to the protection of water resources. In addition to the town-level study, we studied riparian forest loss by watershed to help prioritize locations for targeted educational programs on riparian zone protection and restoration. This targeted outreach has generated considerable interest by town land use boards, and several restoration projects have already resulted. Land cover change information can be a powerful catalyst to watershed protection at both the local and statewide levels.

Riparian Corridors

The ecological and environmental importance of riparian areas is well documented. Often referred to as a transition zone, or ecotone, between two systems (Mitsch and Gosselink 1986; Naiman and Decamps 1997), riparian areas are biologically rich and provide numerous ecological functions. As the interface between aquatic and terrestrial communities, riparian areas are influenced by geomorphology and hydrology. These areas can harbor high biodiversity and provide ecological corridors (Naiman and Decamps 1997; Wenger 1999); they can also perform such functions as stormwater infiltration and filtration, stormwater management, flood water management, streambank stabilization, and sediment trapping (Bentrup 2008; Lowrance et al. 1997; Naiman and Decamps 1997; Wenger 1999). In addition, the combination of surface filtering of sediments, plant and microbial nitrogen uptake, and subsurface denitrification in these areas often makes riparian zones a sink for nitrogen, albeit with tremendous variability resulting from differences in soils, vegetation, buffer width, and other factors (Mayer et al. 2007; Gold et al. 2001). Studies in both urbanizing (Kaushal et al. 2008) and agricultural (Clausen et al. 2000) watersheds have demonstrated that riparian restoration can reduce the delivery of nitrogen to streams.

Because of the many beneficial functions of healthy riparian areas, land cover change in the riparian zone has become a topic of interest. Although the literature is not as robust as that on impervious cover, studies relating stream health to riparian forest cover—sometimes in combination with other land cover metrics—have begun to emerge (Goetz 2006; Goetz and Fiske 2008; Sawyer et al. 2004; Van Sickle et al. 2004; Snyder et al. 2003). For instance, Goetz et al. (2003) found that the best predictor of stream health, as determined by intensive multiparameter chemical and biological stream sampling, was a land cover index that combines watershed impervious cover and riparian area forest cover. Studies such as these typically focus on the site or stream reach level, using detailed data to look at the complex interplay of factors influencing stream health. The present study takes a broader view, making use of a unique, ongoing multitemporal land cover mapping project to focus on riparian corridors throughout Connecticut and to (1) document change in these critical areas over a long period of time and (2) help identify the factors influencing that change.

Methods

This study is an offshoot of Connecticut's Changing Landscape (CCL), an ongoing project of the University of Connecticut's Center for Land Use Education and Research (CLEAR) that

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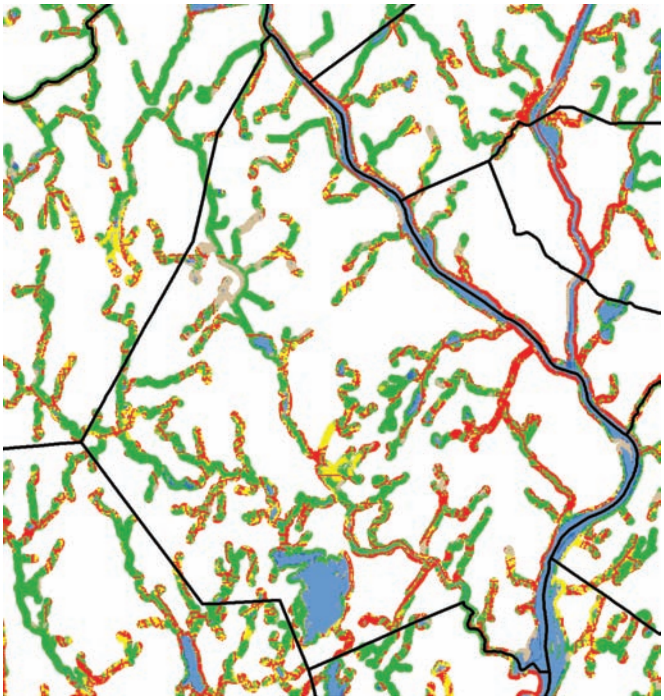

Figure 1. A town-level subset of the study area, showing land cover within a 300-foot (90-m) riparian zone. The area shown is about 200 km^2. Black lines are town boundaries, green areas are forested, red areas are developed land, yellow areas are turf and grass, and blue areas are water.

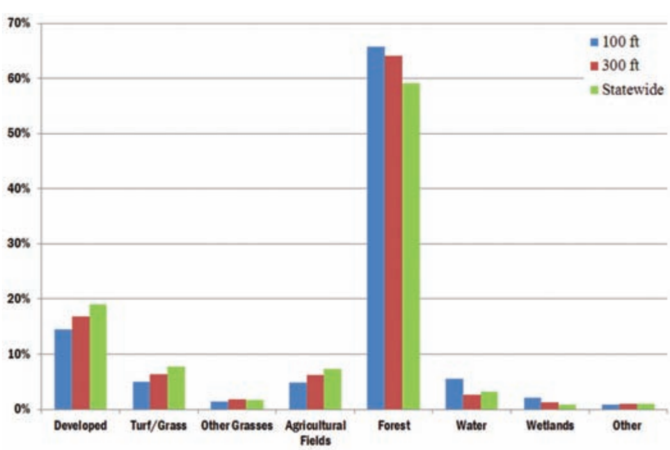

Figure 2. Percentage cover of 2006 land cover categories for the 100-foot riparian zone statewide (blue), the 300-foot riparian zone statewide (red), and the entire state (green).

uses remote sensing technology to chart changes in the state's major land cover categories over time. CLEAR developed the CCL project (see Hurd et al. 2003; CLEAR n.d.[a]) specifically to enable "apples-to-apples" comparisons of multitemporal land cover data sets, all based on 30-m pixel Landsat imagery and dating back to 1985, the first year for which imagery of this resolution is available. Hurd et al. (2003) used cross-correlation analysis—which employs statistical analysis to identify pixels indicating a potential change between images (Koeln and Bissonette 2000)—to produce a consistent set of land cover data sets that one can assess for land cover change over time. They classified the potentially changed pixels and merged them with the 1985 classification to create the 1990 classification; they repeated this process for the 1995, 2002, and 2006 classifications. All five final classification data sets have 12 categories; the major categories of interest are developed land, turf and grass, agricultural field, and deciduous and coniferous forest (Hurd et al. 2003).

In addition to basic land cover change data, CLEAR also has conducted several subsidiary analyses that use the land cover data as the basis for a closer examination of landscape indicators of interest. For instance, CLEAR researchers adapted a landscape fragmentation analysis originally developed by the US Department of Agriculture (USDA) Forest Service (Vogt et al. 2007) for its 30-m data and applied it to Connecticut to go beyond simple forest cover data and provide information on the status of "core forest" areas in the state (Hurd et al. 2010. In another study, researchers analyzed land cover change over areas designated by USDA as having "prime" or "important" agricultural soils and compared it to land cover change statewide (CLEAR n.d.[c]). To this list we add this study, which focuses on land cover change within riparian zones across Connecticut.

We conducted the riparian corridors study by analyzing the CLEAR CCL multitemporal land cover information for areas on both sides of Connecticut streams, lakes, and other water bodies. We created a seamless, continuous GIS data layer of water edges that included not only small stream lines (as determined from statewide hydrography data), but also shorelines of rivers, wetlands, tidal marshes, and water bodies that intersected the stream lines. Thus, rather than follow the stream lines through connected water bodies and wetlands, we used the outside edges of these features as the starting points of the corridor area (Figure 1). To keep the focus on riparian areas and to maintain analytical feasibility, this study did not include inland wetlands and small water bodies that were not directly connected to the stream network. Although the statewide hydrography data can vary from the actual location of smaller streams, the analysis provides a useful overview at the state, town, and watershed levels.

We extracted land cover information for 1985 (T^1) and 2006 (T^2) and the land cover change information for 1985–2006 for this continuous riparian zone. We measured land cover as an area and as a percentage of the unit of interest (the town or watershed), and we measured land cover change as an absolute change (hectares T^2 – hectares T^1), and as a relative change (% area T^2 – % area T^1). The study looked at the riparian zone both 100 feet (30 m) and 300 feet (90 m)[1] to either side of the water features (Figure 1). Since the land cover data have a ground resolution of 100 feet by 100 feet, the 100-foot corridor analysis involves a very small sample size, which we feel approaches the limit of the appropriate use of the land cover data. However, the study included the 100-foot corridor because it encompasses the regulated review zone in many Connecticut towns (see next section). As discussed below, the 100-foot data correlate strongly with the 300-foot data; this raises our confidence in the usefulness of these data.

Results and Discussion

Statewide

We first examined the current (2006) state of land cover for the 100-foot corridor (an area of about 120,700 ha) and the 300-foot corridor (about 343,600 ha) for the state of Connecticut (Figure 2). Statewide, the percentage of forest class increased with proximity to water features. For the 100-foot corridor, forest accounted for more than two-thirds of the area (67.1%); developed land (14.5%) and the closely associated category of turf/grass (5.1%) were the next most prevalent. For the 300-foot corridor, forest was still the most prevalent land cover (64.1%), with developed land (16.8%) and turf/grass (6.3%) again rounding out the top three. By way of comparison, the overall statewide figures from the CCL project were 58.8% forest, 19.0% developed, and 7.7% turf/grass.

We then compared the 2006 data to the 1985 data to evaluate changes in land cover in the riparian zone. Figure 3 shows the change, in hectares, of each major land cover class over the 21-year study period for the 300-foot corridor. The biggest changes were apparent for developed

Figure 3. Absolute change (ha) from 1985 to 2006 in the 300-foot riparian corridor, by land cover class.

land, which increased by more than 7,700 ha, and for forested land, which decreased by more than 10,000 ha. As with the findings in the parent CCL study, the combined increases in the three land cover categories considered by CLEAR researchers to approximate the "urban footprint"—developed, turf/grass, and "other grasses" (13,366 ha)—roughly balance the combined losses to the agricultural field and forest categories (12,940 ha).

A focus on the developed land cover class showed less developed land, and a smaller increase in developed land over the study period, with proximity to water features. Table 1 compares the percentage of the developed class within the 100- and 300-foot corridors with the results for the entire state, as determined by the CCL project. The relative change in developed land was 1.7% for the 100-foot corridor, 2.3% for the 300-foot corridor, and 3.0% for the entire area of the state.

Table 1. Percentage developed land in the 100-foot and 300-foot riparian corridors and for the state as a whole, 1985–2006.

Area of Interest	1985	2006	21-Year Change
100-Foot Corridor	12.7%	14.4%	+1.7%
300-Foot Corridor	14.5%	16.8%	+2.3%
Entire State	16.0%	19.0%	+3.0%

Town-by-Town Assessments

Because land use in riparian areas (as with all areas in Connecticut) is determined at the municipal level, CLEAR also looked at the data by town. One objective was to see if this study could shed any light on the long-term impact of

[1] We use English units for the corridor widths because this is the unit we used in the analysis to better correlate with the regulatory review widths commonly found in town regulations.

inland wetlands and watercourses regulations. Since 1972, Section 22a–42c of the Connecticut General Statutes has required each of the State's 169 municipalities to establish an inland wetlands and watercourses agency. These local bodies are empowered to establish "upland review areas,"[2] within which they may regulate activities based on their impact to wetlands and watercourses. Note, however, that (1) the width of these areas varies from town to town and (2) they are not "no-development" zones but only zones that trigger a review by the local agency. Thus, the consequences of these regulations vary considerably as a result of differences in the local interpretation of a given project's environmental impacts. The Connecticut Department of Environmental Protection estimates that about 80% of the towns have a review zone of 100 feet, and most of the other towns use review areas of 50 to 200 feet; however, a few towns have review zones of up to 600 feet (Connecticut Department of Environmental Protection 2010).

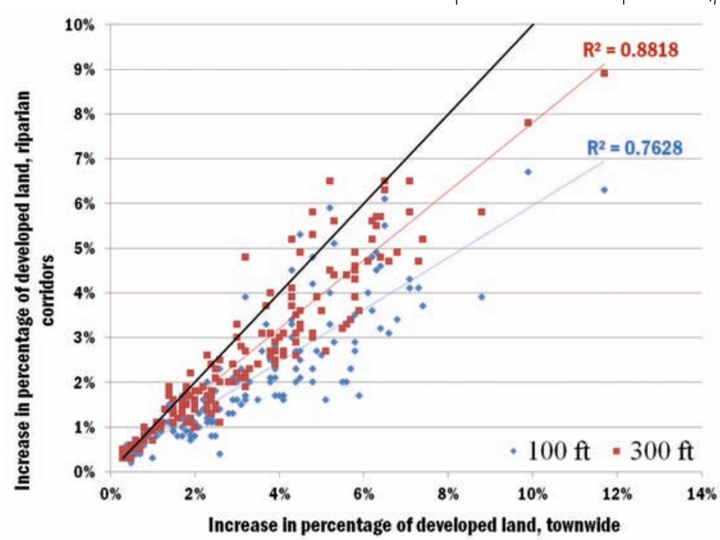

Figure 4. The relationship between the percentage of new development in a town (x-axis) and the percentage of new development in the town's riparian corridors (y-axis) for the 169 towns in Connecticut. Blue points reflect the 100-foot riparian zone, red points the 300-foot zone. Most towns fall below the black line, indicating a higher percentage of development in the town as a whole than in the riparian areas.

This study looked at the relationship between new development in the riparian zones and new development, overall, for each of Connecticut's 169 towns. We plotted the percentage of each town covered by new development during the 1985–2006 period against the same metric for both the 100-foot and 300-foot corridors (Figure 4). The black line in Figure 4 represents a one-to-one relationship between the percentage developed area in the entire town and the percentage developed area in the riparian corridors. That is, a point that falls on the black line denotes a town in which the percentage increase in developed land in the riparian zone is the same as that in the entire town. As Table 1 suggests, most of the data points fall below the black line, indicating that most individual towns had less new development in the riparian areas than in the town as a whole. However, a simple regression analysis shows a very strong correlation between the town and riparian corridor data for both the 100-foot and 300-foot zones. Thus, the greater the amount of new development in a given town, the greater the amount of new development is likely to be in the riparian areas of that town.

The strong, statistically significant correlation between town and riparian development ($p < 0.001$ for both regressions) indicates that local development pressure is a principal factor controlling riparian conversion—not a surprising result. The fact that the relative amount and rate of increase of new development in riparian corridors is lower than in their respective towns, overall, is most likely due to a combination of factors. Local regulation of riparian areas through the state inland wetlands and watercourses program no doubt plays a role in reducing or retarding development near watercourses for particular towns. However, this is surprisingly difficult to prove for several reasons. First, town regulations can change and, if they do, it is highly unlikely that the change will be exactly concurrent with the dates of the land cover data. Also, even with the same review zone regulation, some town commissions are quick to grant a permit while others are more restrictive. Finally, examining town records to track the regulatory history of 169 municipalities is difficult and time consuming. Despite these confounding factors, it seems likely that, if inland wetlands and watercourses regulations were having a widespread effect throughout the state for the past 40 years, one might expect to see additional scatter in Figure 4, created by more uniform low riparian development rates that are independent of local development pressure.

This raises the possibility that lower levels and rates of development in riparian areas may be due more to intrinsic impediments to development than to regulatory factors. To further explore this hypothesis, we used the riparian zone buffer analysis previously applied to our land cover data

[2] Upland review areas are widely known in the state as "buffers." To avoid confusion, we do not use this term when referring to the study area; instead, we use the terms *riparian corridors* or *zones*.

and examined slope and soils within this same zone. Steep slopes (over 20%) and USDA-designated "poorly drained" and "very poorly drained" soils are barriers to development commonly referenced in local zoning codes (B. Hyde, University of Connecticut, pers. comm. March, 2011). As zoning limitations, these are also "regulatory" controls, but they are based on the ability of a given site to support development rather than its potential impact to water or other natural resources.

The 300-foot riparian zone had only a very slightly higher percentage of slopes over 20% (15.8% vs. 15.4% for the state) but contained about twice the amount of poorly or very poorly drained soils (26.5% vs. 13.4%). This lends credence to the supposition that lower levels of development in riparian areas are influenced by building-related zoning restrictions as well as environment-related regulation of wetlands and watercourses.

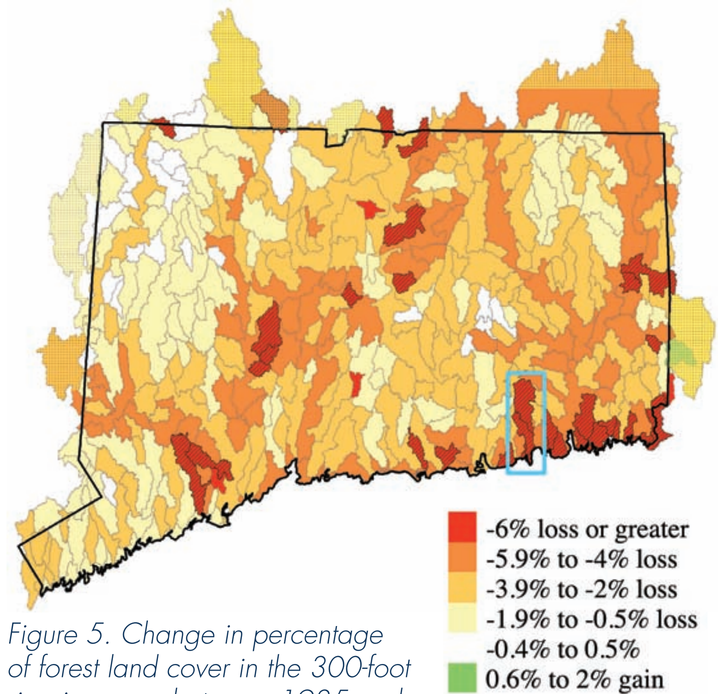

Figure 5. Change in percentage of forest land cover in the 300-foot riparian zone between 1985 and 2006, by watershed. Negative numbers denote a decrease in the percentage of forested land within the riparian corridor of the basin due to the conversion of forest to some other land cover type. The 25 watersheds with the greatest percentage loss in forest in the 300-foot riparian zone are cross-hatched.

Ultimately, this statewide view is of insufficient detail to draw firm conclusions on the impact of local regulations. The wide range of upland review zones, combined with the even wider variability in local interpretation of permissible environmental impacts, makes it extremely difficult to tease out the effectiveness of these laws. Detailed town- and site-level work, involving town hall records rather than land cover pixels, are needed to further advance our understanding of the factors driving riparian conversion. We hope to study the record of land use decisions in several of the outlier towns in Figure 4 to try to determine why the riparian rate of development in these towns is so different from the townwide average.

Assessment by Watershed

We also determined land cover status and change in riparian corridors by watershed, with a focus on the forest land cover class. This study examined the 333 subregional watersheds in Connecticut, a state designation that approximates the US Geological Survey hydrologic unit code 12–level of organization with an average size of about 38 km^2. As previously noted, studies suggest that forest cover in riparian zones can be a good indicator of watershed health, particularly if used in combination with overall watershed metrics like impervious cover (Goetz et al. 2003). The current study simply looked at relative change within the 300-foot corridor of these watersheds during the 1985–2006 study period (Figure 5).

The 25 subregional watersheds with the greatest percentage loss of riparian forest land during the study period appear in several parts of the state, with a noticeable concentration along the southeastern coast. Not surprisingly, these areas correlate closely with areas of overall growth, as determined by the parent CCL project. Of concern to smart growth advocates and others is that these areas are not, for the most part, located along the state's traditional urban corridors, which lie along the southwestern coast and through the middle part of the state.

Making Use of the Data

Based on this analysis and its identification of development "hot spots," the Niantic River watershed along the coast in southeastern Connecticut was identified as a priority area for outreach (Figure 5, blue box). The timing was fortuitous in that the Connecticut Department of Environmental Protection had recently completed a watershed plan for the Niantic, which identified nonpoint source pollution as the primary cause of impaired water quality. In addition, the process of developing the plan had attracted the interest and involvement of both town officials and a local nonprofit, and a watershed coordinator to oversee implementation of the plan had recently been hired. Thus, the Niantic River watershed stood out as an excellent location for riparian area management and protection, both from a practical standpoint and as a model for other watersheds.

With funding from the Long Island Sound Study Futures Fund and the National Fish and Wildlife Foundation, Sea Grant and CLEAR researchers and the Niantic River watershed coordinator developed a series of educational workshops for both municipal officials and local landowners. The workshops used the statewide and local results of the CLEAR riparian zone analysis as a jumping off point to discussing protection and restoration issues. The watershed encompasses four towns, two coastal and two inland, providing the opportunity to discuss not only riparian corridor protection, management, and restoration, but also the ecological importance of, and relationship between, sensitive estuarine and riparian habitats.

In coordination with the environmental planners in each of the four towns, we developed customized riparian workshops for land use commissions. In addition, we conducted two workshops for local land owners, one focusing on coastal habitat and the other focusing on the importance of headwater streams within the watershed. Following these presentations, during the spring and summer of 2010, a dozen Connecticut towns have participated in or requested similar workshops, with more than 400 participants to date. The ability to provide municipal officials with town-specific data and trends developed through the land cover analysis is serving as a unique catalyst for the review and revision of municipal comprehensive plans and regulations. In addition to the protection of riparian corridors, these workshops have sparked interest in on-the-ground riparian area management and restoration projects. Four such projects are underway and will serve as templates for other interested groups. Finally, plans are underway to replicate the Niantic effort in other watersheds identified by this analysis as experiencing the most rapid loss of riparian vegetation.

The riparian corridor analysis is the latest of several studies derived from the CCL project. Based on our experience with prior CCL-related studies, we believe that the data will be widely used. CLEAR's goal is to make the data from all of our land cover studies easily accessible and understandable to a broad spectrum of users, through a combination of direct outreach and project websites. The websites contain information in many formats, from simple diagrams to charts, data tables, and maps, including interactive maps (CLEAR n.d.[b]; Rozum et al. 2005). Land cover change information is used in a variety of ways, from enriching local comprehensive plans, to fueling additional research, to informing state policy. For instance, although only recently completed, the riparian corridor study results have already informed debate in the last two state legislative sessions on whether local inland wetlands and watercourses upland review zones should be made more uniform and transformed into "no-development" areas.

Summary

Connecticut is experiencing urban development in upland areas and critical riparian corridors alike. A 21-year record of directly comparable land cover change enables us to evaluate, on a broad scale, what is happening in these areas. More than 7,700 ha of riparian vegetation in the 300-foot zone was converted to the "developed" land cover class between 1985 and 2006, and another 4,000 ha was converted to turf and grass. The percentage of the landscape in the developed category, and its increase over the 21-year period, are lower within the state's riparian zones than for the state as a whole. This is undoubtedly due to the influence of a complex combination of jurisdictional and intrinsic landscape factors. Although this study did not definitely determine the exact interplay of the drivers behind this change, the results show a strong correlation between development rates in riparian zones and those of the towns in which the riparian zones are located; this suggests that local development pressure is chief among the driving factors. Secondary factors that may explain the lower amounts and rates of development in riparian zones include local regulation of development based on suitability for building, probably enhanced by local regulation based on possible impacts to wetlands and watercourses. Detailed town-by-town analysis is needed to determine the true nature of these relationships.

Land cover data generated at a resolution of 30 m may seem almost mundane in a world where high-resolution imagery is readily available on personal computers and mobile devices. However, our 20-year experience at CLEAR, reinforced by our work to date with the riparian study, demonstrates that these data can be very effective at stimulating discussions about sustainable land use plans and regulations and catalyzing changes to those plans and regulations.

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