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On the cover:
Lake Winnisquam in Tilton, New Hampshire, is one of the larger lakes in New Hampshire, and one where shoreline development, shoreland clearing, and competing uses are at the forefront of issues. Photo by Amy Smagula.

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Examining Shorelines, **Littorally**

Kellie Merrell, Eric A. Howe, and Susan Warren

The Effects of Unbuffered Lakeshore Development on Littoral Habitat, or – More Accurately – Littoral Biotope

Why Study Lake Shorelines?

The littoral zone is an important part of the lacustrine ecosystem as it forms a transition zone between the terrestrial and aquatic environment. However, despite the increasing frequency in which the importance of the littoral zone appears in the published literature, there are few management programs that have incorporated the littoral zone into their routine monitoring operations. The littoral zone functions as a nursery ground for a variety of species and as primary habitat for aquatic plants. It serves as a critical interface between the aquatic and terrestrial environment for the transport of nutrients, sediment, woody substrate, organic matter, and species that utilize both lake and land.

Since the mid-1980s there has been substantial shoreline redevelopment on lakes. The transformation of lakeshores from their natural forested and wetland cover to newly developed lawn and sandy beaches, and the conversion of summer cottages to residential homes is a stressor to littoral zones in lakes. In the early 1990s, the U.S. Environmental Protection Agency and U.S. Fish and Wildlife Service concluded from a study of 345 northeast lakes that the stress from shoreline alteration was a more widespread problem than eutrophication and acidification (Whittier et al. 2002).

In Vermont, removal of the vegetated lakeshore buffer is not prohibited by state law, and approximately nine percent of the towns have shoreland vegetation protection in their zoning laws. The University of Vermont's Spatial Analysis Laboratory mapped shorelines within 25 feet of the waters' edge for 74 lakes in the Northern Forest of Vermont. The results indicated that, as of 2003, lakeshore development had impacted the vegetated buffer on up to 74 percent of a lake's shoreline (Capen et al. 2008). From 2005-2008, the Vermont Department of Environmental Conservation (VT DEC) conducted a study to measure what, if any, effects unbuffered development has on littoral aquatic habitat.

What Do We Mean by "Littoral Biotope"?

The littoral zone is the area of a lake where light penetrates to the bottom, usually in the near-shore shallow water environment. "Habitat" is a commonly used term in ecological studies, but its definition varies with different disciplines of ecology and natural resource management. *Autecologists* (species ecologists) define habitat as species-specific, yet that is not the habitat we are addressing. *Biotope* can be defined as the sum of the physical, chemical, and biological components present in an area providing a living space for a distinct, recurring community of species (Tillin et al. 2008). Literally translated, biotope means "the area where life lives." Hence, to avoid confusion, we will use "biotope," a term used as a synonym for habitat by the "father of modern limnology" (Hutchinson 1957) in this article.

What We Surveyed in Vermont Lakes and Ponds

In this study, we used the reference approach as defined by Tillin et al. (2008) to assess how the littoral biotope is altered by development that removes the natural shoreline vegetation. This approach assumes that littoral biotopes subjected to little or no anthropogenic shoreline alterations represent the best physical, chemical, and biological "natural" condition in the littoral zone. These sites were considered high quality and are referred to as "reference sites." The quality of the littoral habitat adjacent to unbuffered developed lakeshore sites was then measured as the degree to which conditions within it departed from the "natural" or reference state. These treatment sites are referred to as "unbuffered developed sites."

Our study contains results from surveys conducted on 40 lakes across Vermont. We surveyed lakes comprising three trophic classes: oligotrophic, mesotrophic, and dystrophic. We divided these classes further by lake surface area into small lakes (<200 acres) and large lakes (>200 acres). We avoided artificial lakes and lakes with significant drawdowns because we felt that the natural biotope conditions were compromised in these lakes and would not meet our criteria for reference condition. We visually selected unbuffered developed sites for each lake, and corresponding undeveloped reference condition sites with similar exposure, slope, and sediments. We surveyed a total of eight sites on each small lake and a total of 12 sites on each large lake. We attempted to pair every developed site with a reference site, but lakes with little to no development had more reference sites and lakes with little undeveloped shore had more unbuffered developed sites. In total, we sampled 234 reference sites and 151 unbuffered developed sites. At each site we placed a 10-m floating transect line at the 0.5-m depth contour and ran it parallel to the shore.

The transect was then divided into two 1-m wide by 5-m long plots. Snorkelers estimated the percent cover of a number of physical and biological parameters within each plot (Figure 1). Transects were also laid at 1-m and 2-m depths to capture the full diversity of aquatic plants within the near-shore littoral zone. Results presented here focus on the 0.5-m transect results (the transect nearest shore) and therefore most directly influenced by adjacent terrestrial conditions.

Let's define the littoral biotope in the context of what we examined in this study. We observed the biotope as the shallow nearshore area of a lake and took measurements of the physical, chemical, and biological components in that area. There are many important chemical properties that control what life exists there. For this study, we focused on nutrient enrichment (trophic condition) and alkalinity as important chemical defining features. We identified and selected dystrophic, high alkalinity oligotrophic, and high alkalinity mesotrophic lakes for use in this study. VT DEC has been collecting this water quality information since 1977, which enabled us to focus on lakes with these specific water chemistries.

There are many important physical properties that control what life exists in the littoral zone. The size and shape of the lake can influence the intensity with which the littoral zone experiences wind-driven wave activity; hence, we separated lakes into large (>200 acres) and small (<200 acres) classes. In the field, we estimated the percent cover of trees along the shore parallel to the littoral transects at each site. We also measured shading of the littoral zone at 1 m from shore using a densiometer. Our densiometer measured shading as a range from 0 to 17, with 17 representing 100 percent shaded. We counted the number of pieces of large (>10 cm diameter) woody structure in the littoral zone of the site from the waters' edge out to the 2-m depth transect. In each transect plot we recorded percent cover of fine (<4 cm diameter) and medium (4-10 cm diameter) littoral woody structure, deciduous leaf litter, sediment type (sand/gravel, silt, cobble, rock/bedrock, muck, woody detritus, floc), and sediment embeddedness.

Finally, there are the biological components of the littoral biotope.

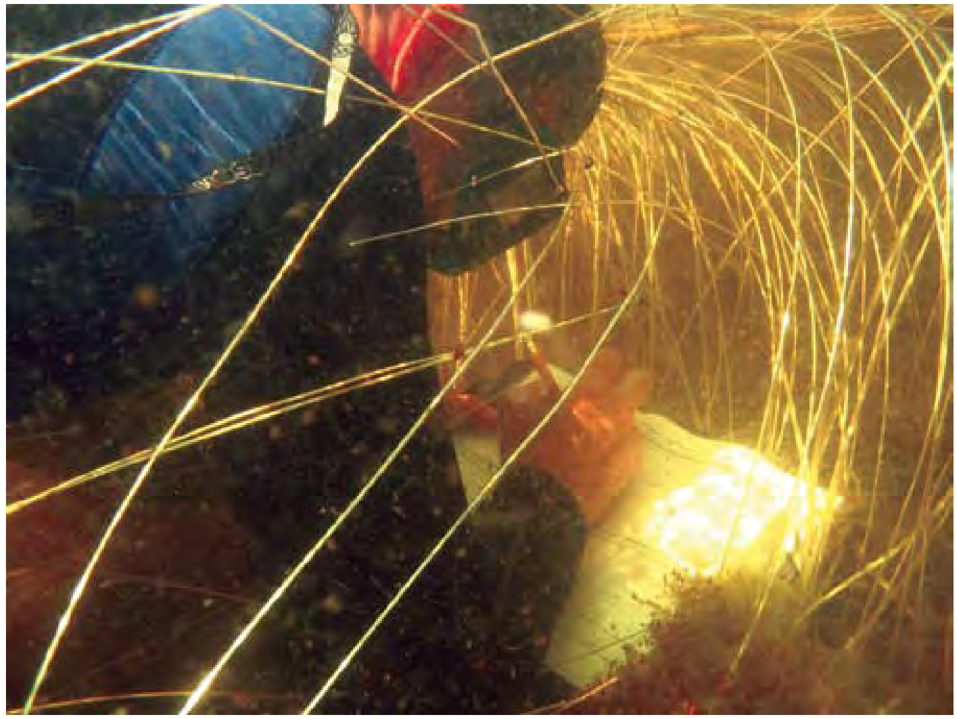

Figure 1. Snorkeler recording aquatic plant data.

"Aufwuchs" is the term that describes the community of small plants and animals that form biofilms on rocks, woody substrate, and aquatic plants (Figure 2). Aufwuchs is an important food base for fish and macroinvertebrates. We measured the percent cover of aufwuchs on solid surfaces (i.e., sediments and woody substrate), in each plot. Dragonfly and damselfly (odonates) larvae are another important biological component of the littoral biotope, as they feed on aufwuchs, and become prey for fish and other vertebrates. Odonate *exuviae* are the skins left behind by these insects when they crawl out of a lake in their larval form and transform into their adult winged terrestrial form (Figure 3).

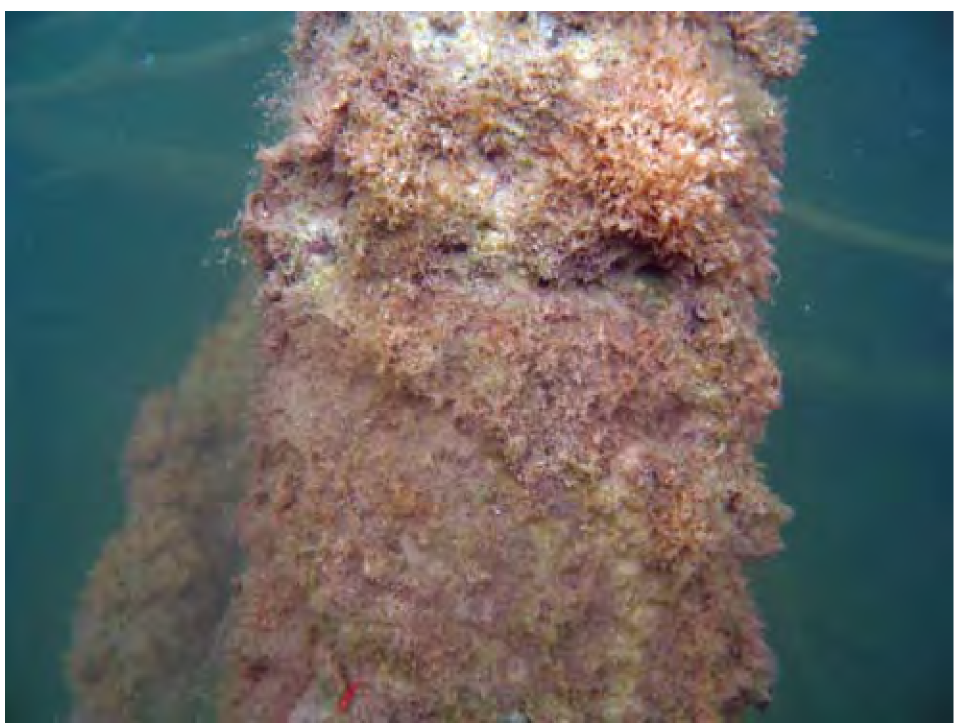

Figure 2. Aufwuchs living on piece of large woody structure.

Figure 3. Larval odonate exuviae (skin) left behind after adult damselfly emerged.

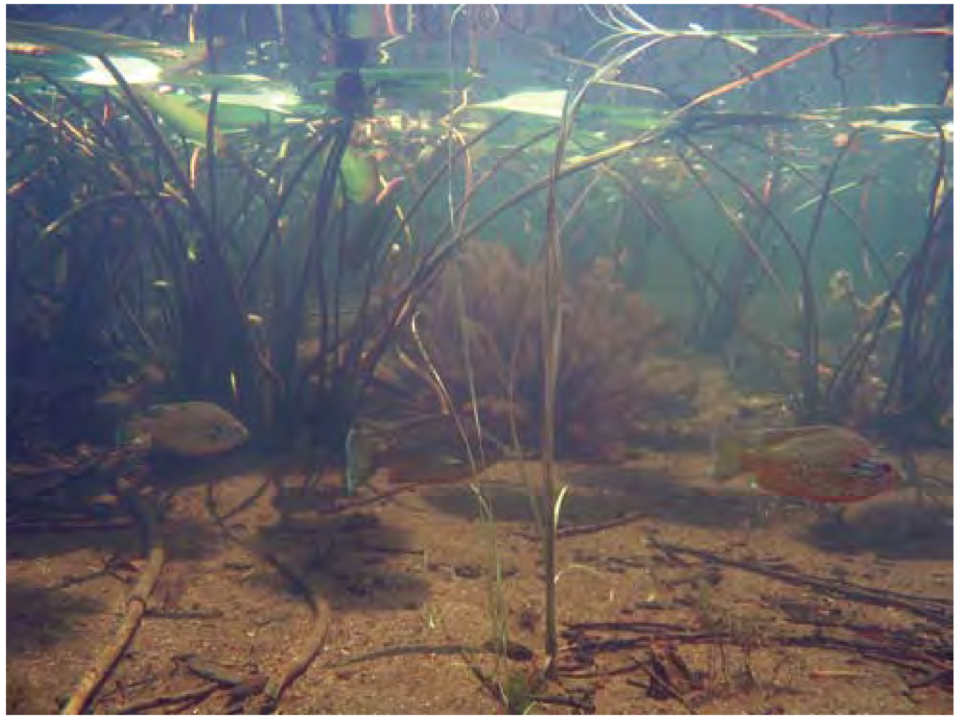

Figure 4. Aquatic plants providing physical structure and food supply for other aquatic biota.

These insects have habitat requirements for both the aquatic littoral zone and the terrestrial shoreline. We collected all exuviae from along the 10-m shoreline transect and 2-m inland at each site. The final biological component of the littoral habitat we measured was the percent cover of aquatic plants (macrophytes) in each transect plot. Aquatic macrophytes are important in defining biological components of the littoral zone. They influence both the chemistry (through nutrient uptake, oxygen production during the day, and respiration during the night) and also function as physical structural components within the littoral biotope (Figure 4).

Is There an Observed Biotope Change at Unbuffered, Developed Sites?

We accounted for a total of 13 defining littoral biotope components in this study (Table 1). Three were predetermined by our selection of lake classes using lake size, trophic state, and alkalinity range. The remaining ten components were measured at each site. With the exception of aquatic plant cover, means of these measured biotope components at unbuffered developed sites were significantly different from their respective mean reference condition biotope components (Table 2, Figure 5).

The differences in all of the biotope components between the reference sites and unbuffered developed sites were substantial. We used relative percent differences to express these observed differences because we thought it more aptly conveyed the change as experienced by the biological community that had evolved to inhabit the reference condition (Figure 6). We calculated the relative percentage difference between the mean values of reference vs. unbuffered developed conditions for each of the ten measured biotope components. Figure 6 illustrates the percent deviation from the reference biotope. There was 182 percent less shoreline tree cover at unbuffered developed sites. This factor explains the majority of the observed differences for all of the other parameters evaluated

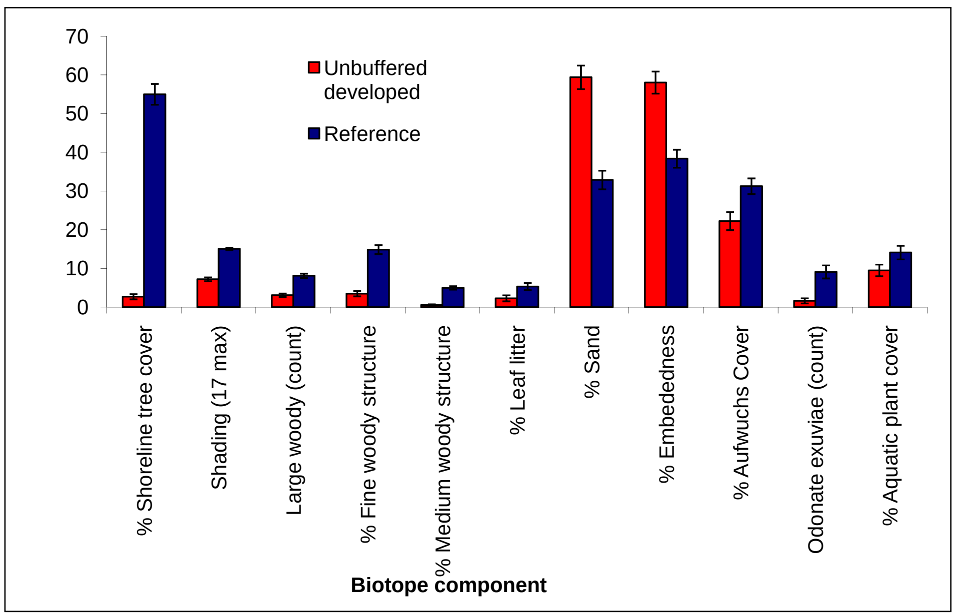

Figure 5. Mean values (±1 SE) for shading at 1 m depth (0-17), count of large woody structure and odonate exuviae, and mean percent cover of shoreline trees, fine and medium woody structure, leaf litter, sand, embeddedness, and aufwuchs.

Table 1. Components of the Littoral Biotope Examined in This Study, Ranges for the Component Values, and Method of Data Collection.

Biotope Component	Range of Measurement	Data Collection Method
Chemical		
Trophic state	Dystrophic, oligotrophic, mesotrophic	VTDEC lake monitoring database
Alkalinity	>12.5 ug $CaCO_3$/liter for meso- & oligotrophic	VTDEC lake monitoring database
Physical		
Shoreline tree cover	0-100% cover	Estimated along 10 m of shore transect
Shading	0-17, where 17 =100% shaded	Collected 1 m from shore
Large woody structure	Count	Counted all pieces >10 cm diameter from shore to 2 m depth
Medium woody structure	0-100% cover	Estimated in 0.5 m depth transect plots
Fine woody structure	0-100% cover	Estimated in 0.5 m depth transect plots
Leaf litter	0-100% cover	Estimated in 0.5 m depth transect plots
Sediment type	% cover for sand/gravel, silt, cobble, rock/bedrock, muck-organic, woody detritus, floc	Estimated in 0.5 m depth transect plots
Embeddedness	0-100% embedded	Estimated in 0.5 m depth transect plots
Biological		
Aufwuchs	0-100% cover	Estimated in 0.5 m depth transect plots
Aquatic plants	0-100% cover	Estimated in 0.5 m depth transect plots
Odonates	Count	Collected all exuviae along shore

Table 2. Biotope Component Mean, Standard Error, Number of Sites, and Statistical Significance (< 0.05) Across All 40 Study Lakes for All Unbuffered Developed and Reference Sites.

	Unbuffered Developed			Reference				
Biotope Variable	**N**	**Mean**	**SE**	**N**	**Mean**	**SE**	**F-stat**	**P-value**
Shoreline % tree cover	150	2.7	0.68	234	55.0	2.70	12.29	<0.0001
Shading 1 m	151	7.2	0.49	229	15.1	0.31	354.61	<0.0001
Large woody count	151	3.1	0.44	231	8.1	0.56	49.42	<0.0001
% Fine woody cover	151	3.5	0.69	234	14.9	1.17	70.07	<0.0001
% Medium woody cover	151	0.6	0.17	234	5.0	0.45	84.18	<0.0001
% Leaf litter	151	2.3	0.78	234	5.3	0.88	6.75	0.0097
% Sand	151	59.4	3.05	234	32.9	2.40	46.71	<0.0001
% Embeddedness	151	58.0	2.86	234	38.4	2.34	28.43	<0.0001
% Aufwuchs cover	151	22.2	2.32	234	31.2	2.02	8.53	0.0037
Odonate exuviae count	151	1.6	0.66	234	9.1	1.68	17.10	<0.0001
% Aquatic plant cover	151	9.5	1.52	234	14.1	1.76	1.44	0.1474

in this study. With respect to the other physical components, there was 71 percent less shading in the littoral zone off the unbuffered developed sites. Less shading of the water means warmer water temperatures and more exposure to predation from visual avian and terrestrial predators.

There was also 90 percent less large woody structure in the littoral zone at unbuffered developed sites, providing less cover for fish. This reduction also means there is less vertical substrate available for amphibians and fish to attach their eggs to so they will remain well oxygenated above the lake bottom. Less large woody structure also means fewer basking sites for turtles that are safe from terrestrial predators (basking helps reptiles regulate their body temperature and save energy for reproduction). There was 124 percent less fine woody structure off unbuffered developed sites. This substrate is important to macroinvertebrates; it serves

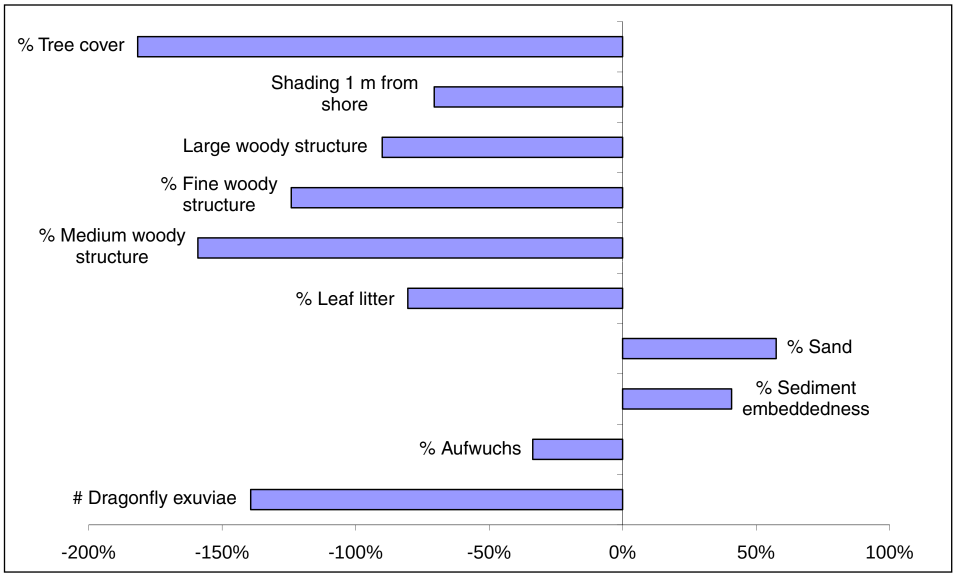

Figure 6. Relative percent difference of unbuffered developed sites from reference sites for ten biotope parameters

as cover from predation, material from which caddisflies make their casings, and substrate for microorganisms that form the foundation of the food chain. Of the three woody structure size classes, medium-sized branches and sticks were the most reduced off unbuffered developed sites. These unbuffered developed sites had 159 percent less woody structure than reference sites, representing a reduction in the cover and ecological functions of the medium woody structure class. There was 80 percent less deciduous leaf litter in the shallow littoral zone of unbuffered developed sites, further reducing the available substrate for macroinvertebrates and microorganisms. The sediment structure was altered off of unbuffered developed sites as well, with the addition of 57 percent more sand and 41 percent more sediment embeddedness of rocks and woody material.

The differences in the biological components measured were also striking. There was, on average, a 34 percent reduction in aufwuchs at the unbuffered developed sites compared to the reference sites, meaning less food is available for fish, snails, and macroinvertebrates. There were 139 percent fewer odonate exuviae skins at unbuffered developed sites. This represents an additional reduction in prey for fish and a reduction in the number of emerging dragonflies and damselflies into the terrestrial ecosystem.

Aquatic macrophyte abundances were also changed by unbuffered development, but physical and chemical components helped determine what that change would look like. In small oligotrophic and mesotrophic lakes, unbuffered developed sites had greater aquatic plant cover than reference sites, whereas in large mesotrophic, large oligotrophic, and dystrophic lakes, unbuffered developed sites had less aquatic plant cover. Aquatic plant cover was the only biotope component with a response to unbuffered development that varied with the predefined trophic and lake size classes (Figure 7).

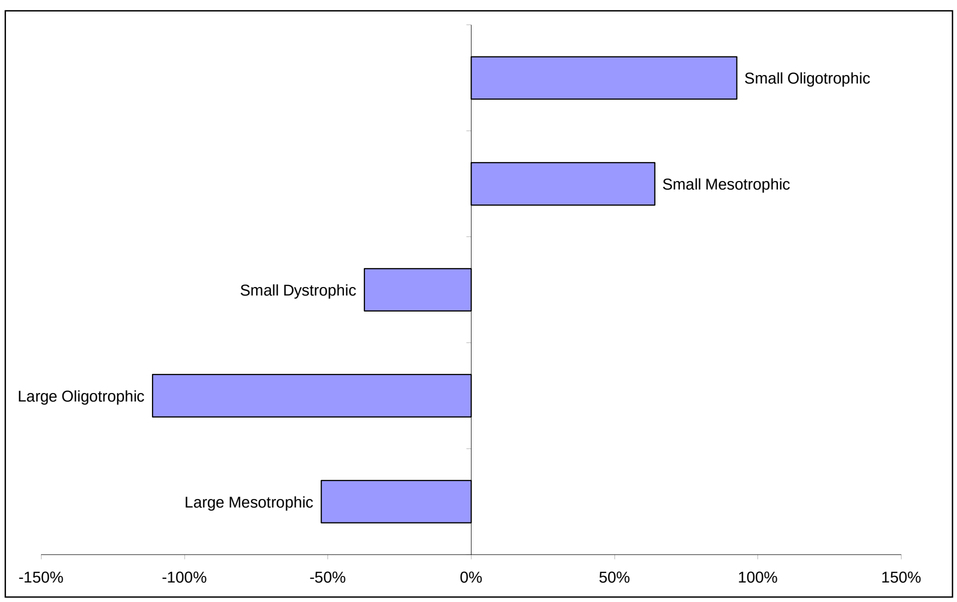

Figure 7. Relative percent difference in mean aquatic plant cover for dystrophic lakes and small and large oligo- and meso- trophic lakes at unbuffered developed sites from reference sites at 0.5-m depth.

In summary, conversion of treed shorelines to lawn may seem harmless to humans, but the chemical, physical, and biological components of the littoral biotope are radically changed by this activity. The natural community of aquatic and terrestrial organisms that has evolved to grow, reproduce, and survive there will change or disappear as the biotope undergoes the physical, chemical, and biological transformation to something with substantially diminished habitat quality. Minimizing the extent of shoreline conversion from forested land to lawns within the buffer zone and maximizing the extent of naturally buffered shores will help ensure that the natural community of lacustrine species endures.

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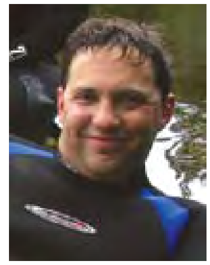

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