Lakeshore Development Patterns in the Northern Forest of Vermont and Implications for Water Quality

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Primary Conclusion: Lakeshore development in the Northern Forest adversely affects water quality and aquatic habitat at multiple scales (littoral zone and lakewide)

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Project Summary

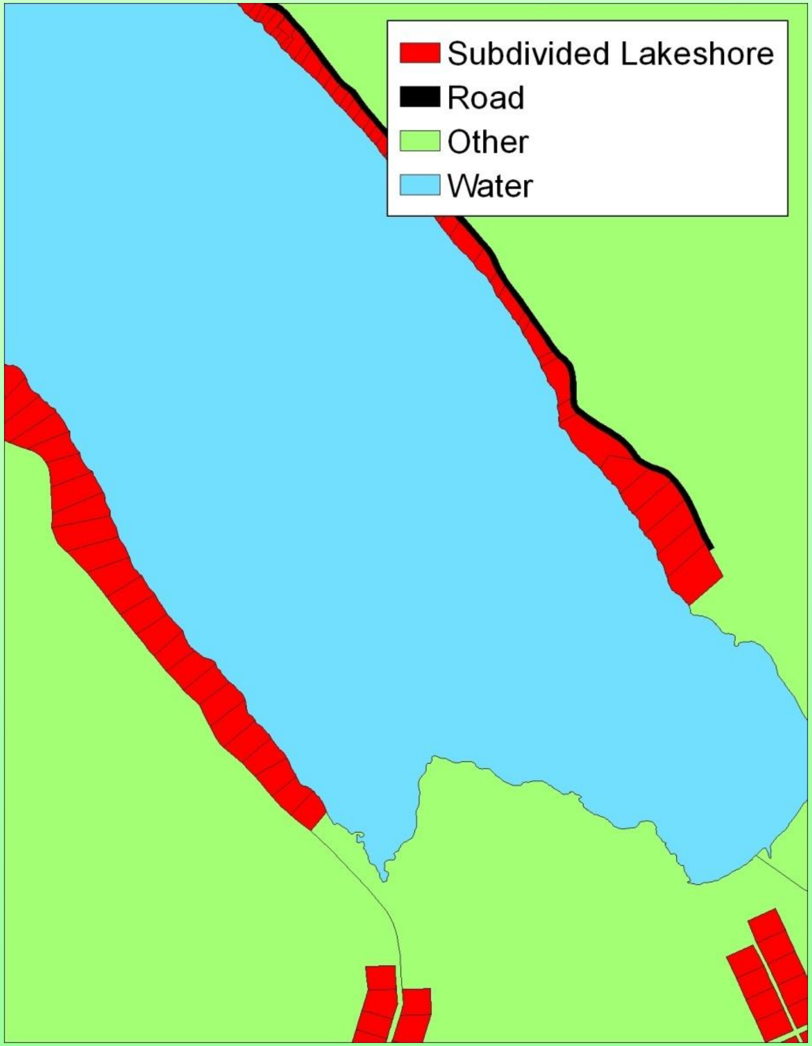
Lakeshores in the Northern Forest of Vermont are sensitive ecological zones that provide essential habitat for numerous terrestrial and aquatic species, and they also protect water quality by preventing erosion and filtering nutrients. However, the aesthetic qualities of lakeshores also make them attractive locations for second homes and camps, often making lakeshore property more valuable as real estate than forestland. In conjunction with changing land-ownership patterns in the Northern Forest, these economic realities have facilitated subdivision of lakeshores for residential development and associated infrastructure. To protect Vermont's remaining undeveloped lakeshores, it is thus necessary to quantify the current extent of development around lakes, demonstrate a relationship between landscape patterns and water quality, and examine specific near-shore habitat characteristics that are affected by shoreline changes.

Accordingly, we conducted a lakeshore assessment at two scales: 1) littoral habitat at specific sites; and 2) landscapes encompassing entire lakes. First, we mapped land-use/land-cover (LULC) patterns for a representative selection of lakes in northeastern Vermont (74 lakes), creating 12-class LULC maps within a 600-m buffer for each lake. We then collected littoral-zone habitat data for a subset of these lakes, including woody debris, embeddedness, and aquatic vegetation. Finally, we used landscape characteristics derived from the LULC maps, littoral-habitat data, and existing water-quality datasets to develop statistical models linking development patterns to environmental-quality indices.

Lakeshore segments that are both undeveloped and unprotected were identified by comparing LULC maps to conserved lands data. Statistical modeling at both the site- and landscape-scales indicated that landscape slope, level of urban development, quantities of un-impacted shorelines, and lake morphometry all factor into both the quality of available biotic habitat and overall lake health. These results demonstrate the importance of conserving stretches of undeveloped shorelines on the lakes of northeastern Vermont.

This information provides an objective basis for effective conservation planning, baseline data for monitoring development patterns, and additional quantitative evidence demonstrating the adverse effects of lakeshore development. It will also assist regulatory and outreach efforts by further illustrating the ecological value of intact lakeshore segments.

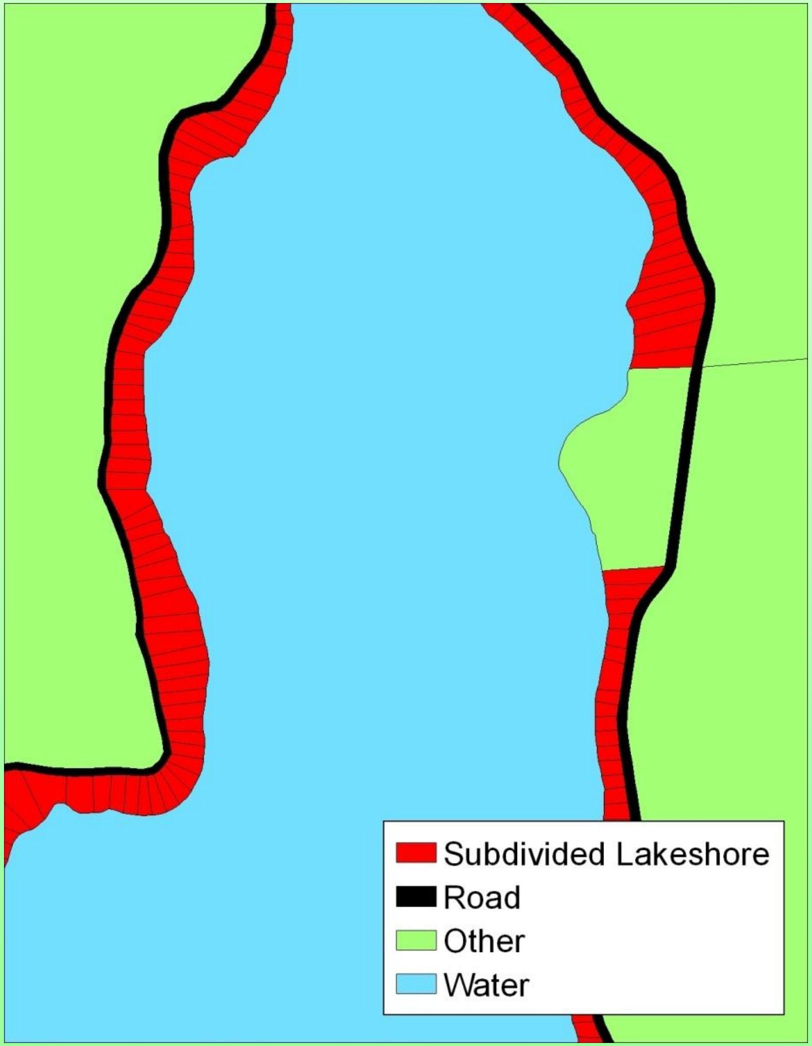
Background and Justification



Subdivision in a Northern Forest lakeshore zone

- Land ownership patterns changing rapidly in the Northern Forest
- Some forestlands more valuable as real estate, especially areas that are desirable locations for vacation homes (e.g., lakeshores and ridges with views)
- Real estate values drive subdivision of lakeshore zones and subsequent residential development
- Another trend: seasonal camps and cottages along lakeshores are being converted into year-round homes
- Increased volume and intensity of lakeshore development directly affects terrestrial wildlife habitat and may also reduce water quality and aquatic habitat

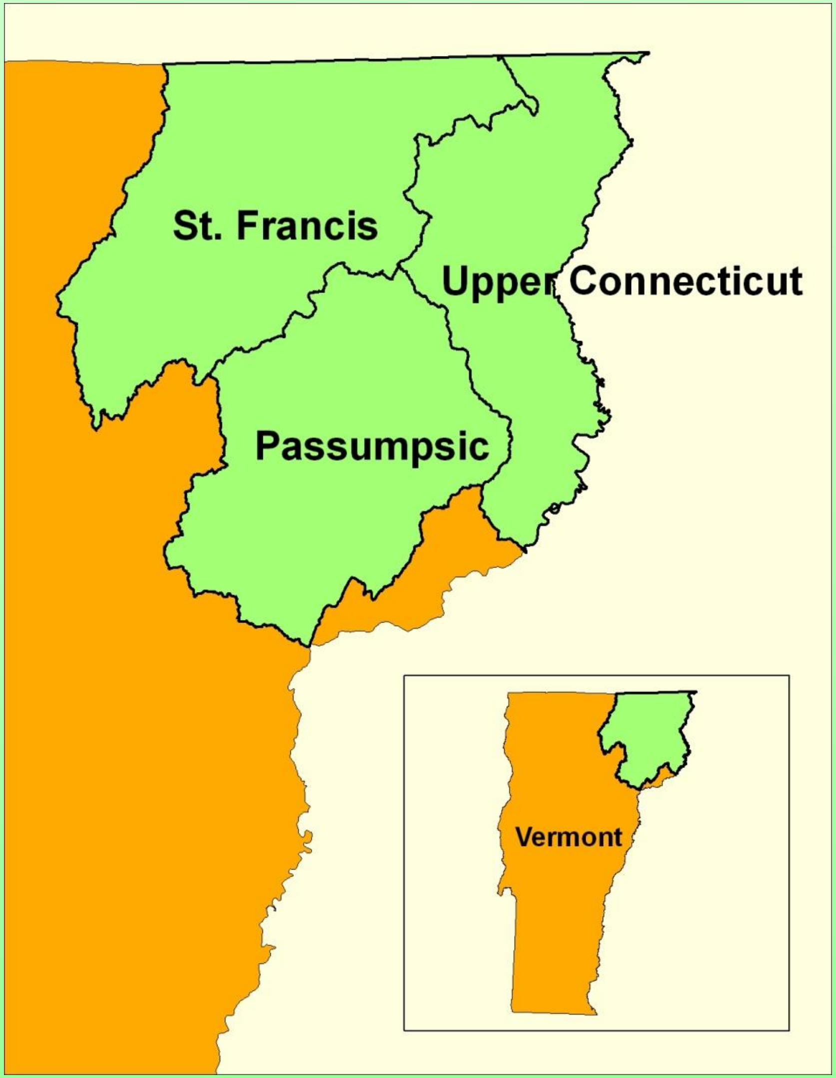
Background and Justification



Subdivision pattern in a Northern Forest lakeshore zone

- Urgent need to quantify current extent of development and possible effects
- Provide baseline for monitoring trends
- Provide data for deliberations on possible regulatory restrictions (e.g., lakeshore buffers)
- Focus conservation-planning efforts by identifying undeveloped shorelines that are also unprotected
- Establish protocols for examining the effect of landscape-level changes on water quality
- Develop sampling methods for studying sensitive littoral habitat (a relatively new emphasis in lake monitoring)

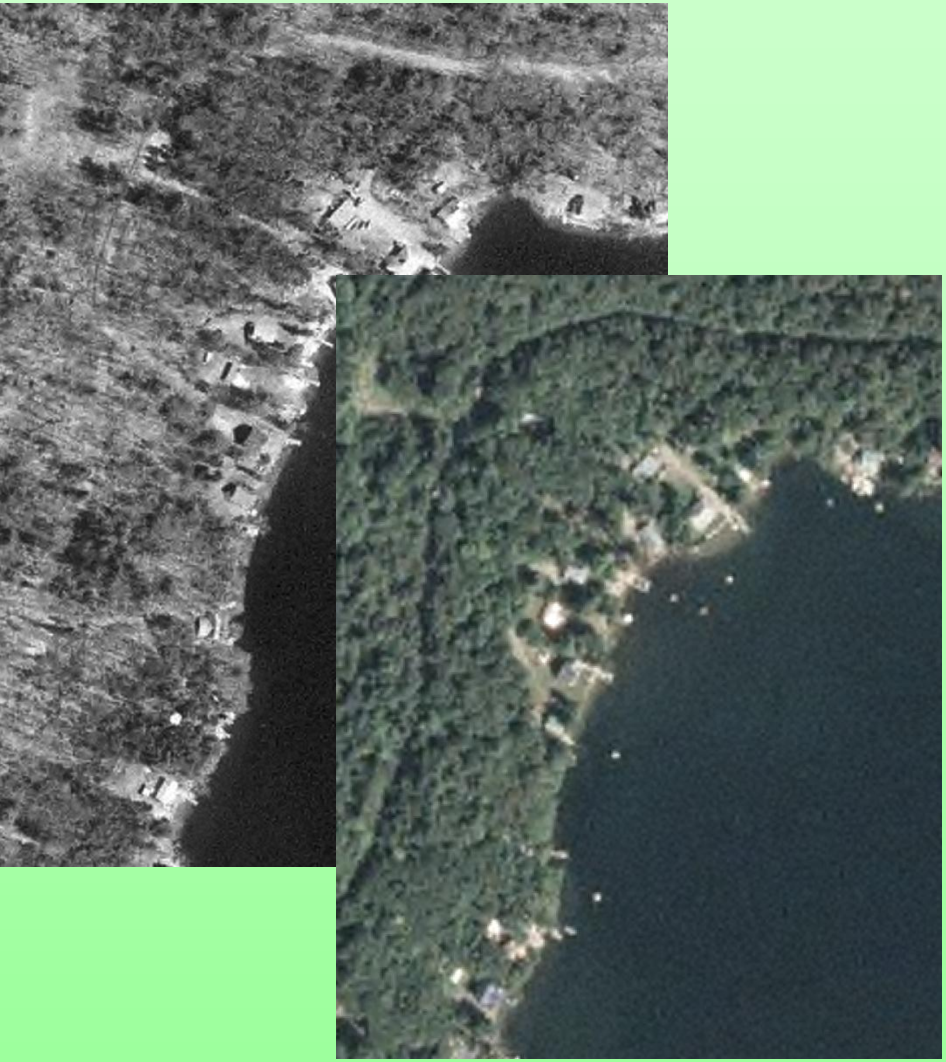
Objectives



Primary study area in the Northern Forest of Vermont

- Develop comprehensive land-use/land-cover (LULC) maps for a representative set of lakes
- Compare lakeshore development trends to an earlier study
- Identify undeveloped, unprotected lakeshores
- Collect habitat data for littoral zone (shallow water immediately adjacent to shoreline)
- Examine relationship between lakeshore-development patterns and water quality and aquatic habitat variables
- Multiple-scale analysis: landscape and site levels

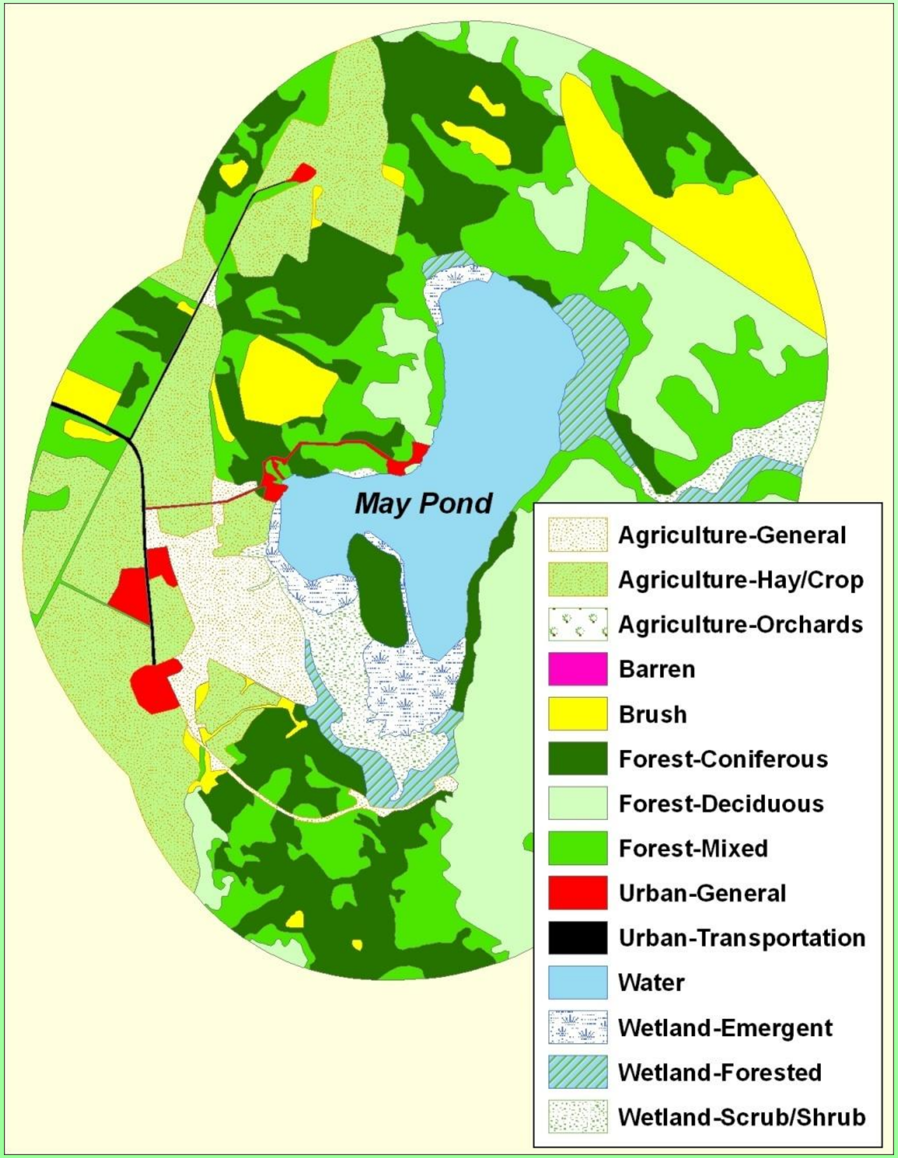
Land-use/Land-cover Mapping: Methods



VMP and NAIP orthophotographs for an example lakeshore segment

- Lakes selected to ensure multiple trophic levels (oligotrophic, mesotrophic, eutrophic), size classes (minimum: 10 acres), and development levels
- Mapping based primarily on Vermont Mapping Program (VMP) digital orthophotography quadrangles (1990s, B&W, 1:5000, leaf off)
- National Agricultural Imagery Program (NAIP) orthophotographs (2003, True Color, 1:40,000, leaf on) also used
- LULC mapped within a 600-m buffer around each selected lake (onscreen digitizing)
- 12-class LULC maps (various forest, wetland, agricultural, and developed categories)

Land-use/Land-cover Mapping: Results

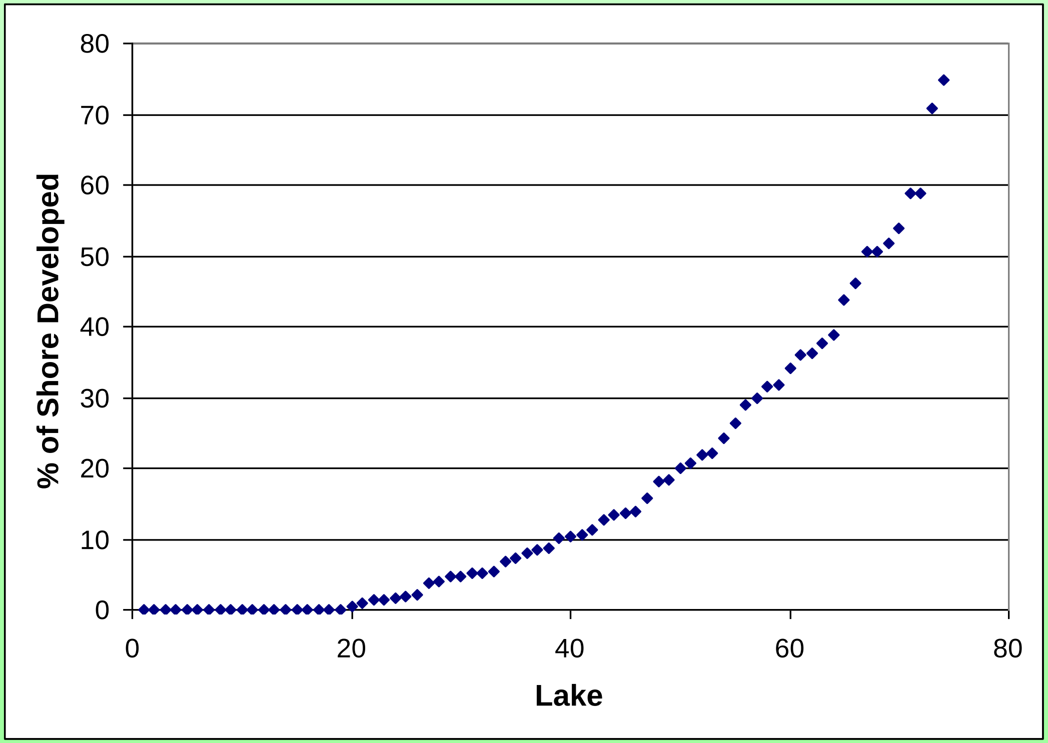


Lakeshore LULC map for May Pond

- 74 lakes mapped
- 66 lakes in primary watersheds (St. Francis, Passumpsic, Upper Connecticut)
- 8 lakes in immediately-adjacent areas in other watersheds: Lamoille, Winooski, Connecticut (Johns River to Waits River)

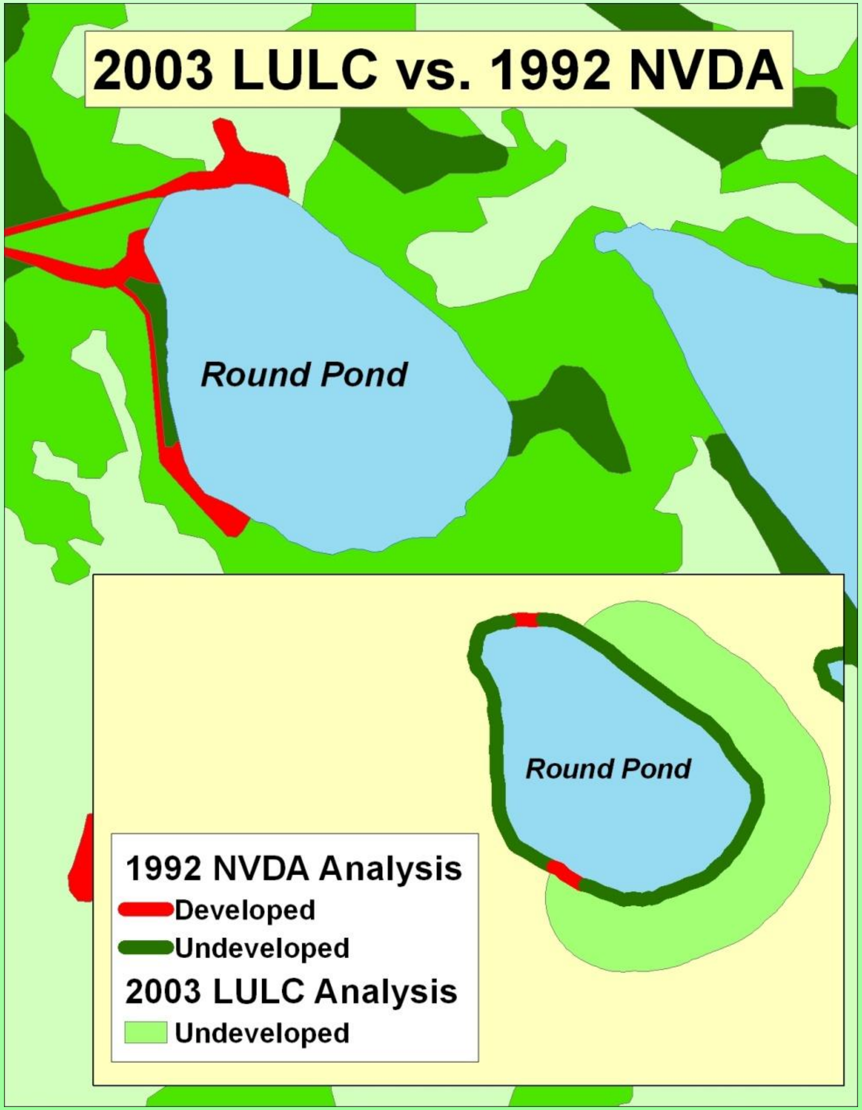
Land-use/Land-cover Mapping: Results

Development within a 50-ft (15.2-m) Buffer



- Of 74 mapped lakes, 8 lakes had >50% developed lakeshore (as a percentage of the 50-ft buffer around each lake), circa 2003
- 28 lakes had >10-50% developed lakeshore
- 19 lakes had >0-10% developed lakeshore
- 19 lakes had no developed lakeshore

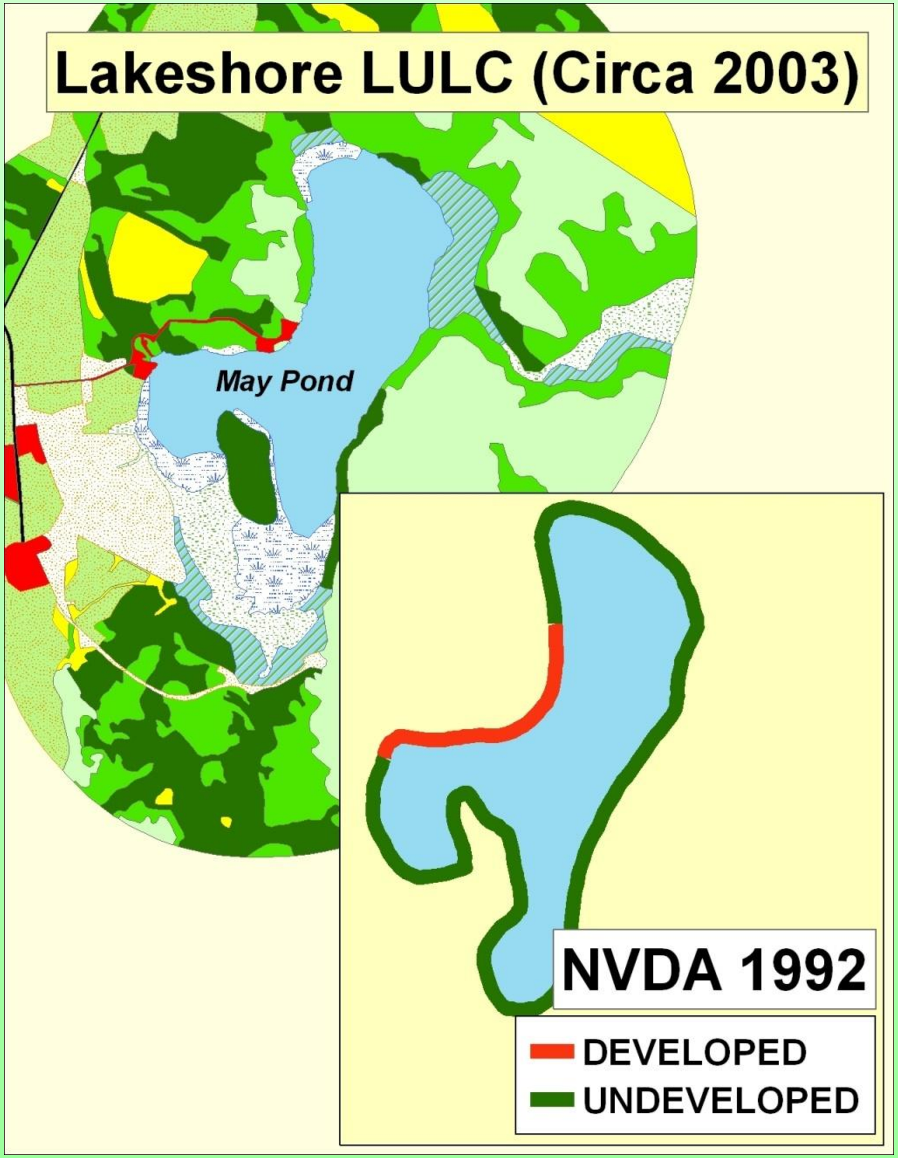
Comparison to 1992 NVDA Study: Methods



Comparison of 2003 LULC Map for Round Pond (Sheffield) to 1992 NVDA Analysis

- Northeastern Vermont Development Association (NVDA), a regional planning commission, inventoried undeveloped lakeshores in 1992 (lakes > 10 acres)
- NVDA definition: shorelines at least 1,000 ft (304.8 m) long and 250 ft (76.2 m) wide with no human structures or 2-wheel drive roads (agricultural fields considered undeveloped)
- Inserted NVDA lake boundaries into LULC maps to ensure consistency
- Estimated undeveloped shoreline segments circa 2003 using NVDA definition
- For each lake, calculated undeveloped shoreline as a percentage of total shoreline

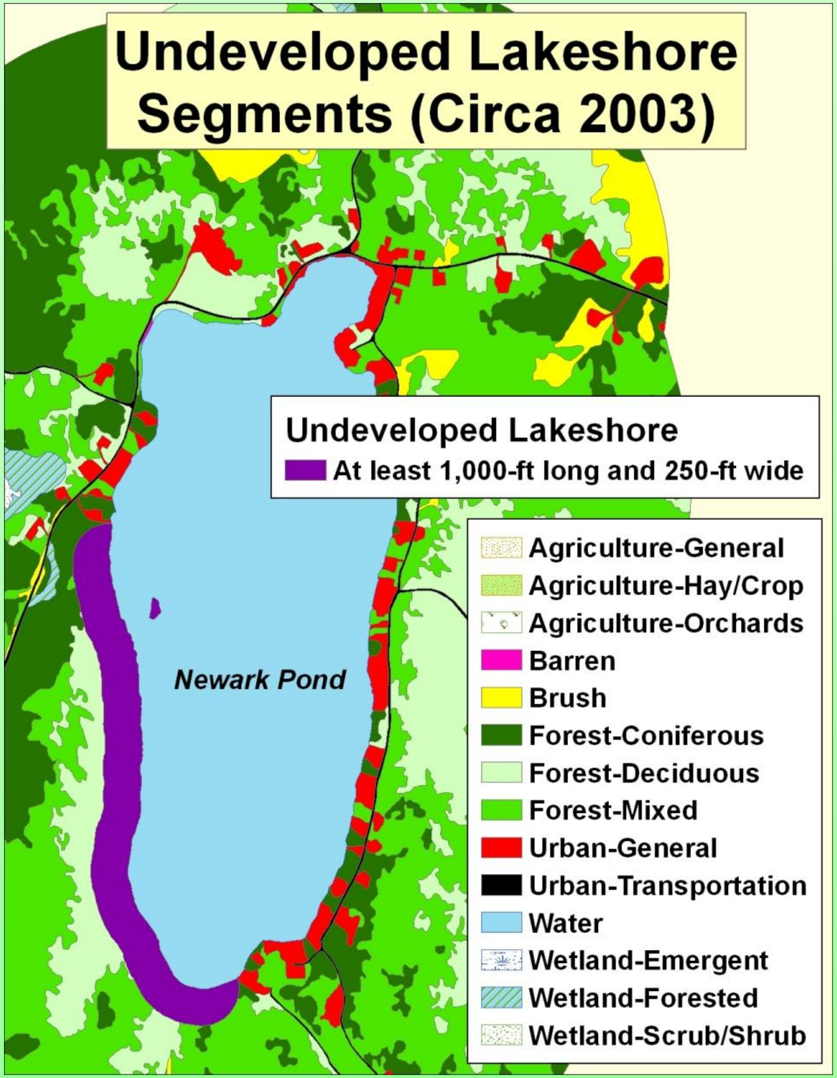
Comparison to 1992 NVDA Study: Results



Comparison of 2003 LULC to NVDA 1992 for May Pond

- 68 lakes represented in both studies
- Proportion of undeveloped shoreline decreased by more than 10% in 10 lakes, increased in 8 lakes, and was unchanged in 50 lakes
- Variable results (i.e., increases in undeveloped shoreline) indicate that methodological differences hindered accurate comparison
- Circa 2003 lakeshore maps will serve as objective basis for future assessments

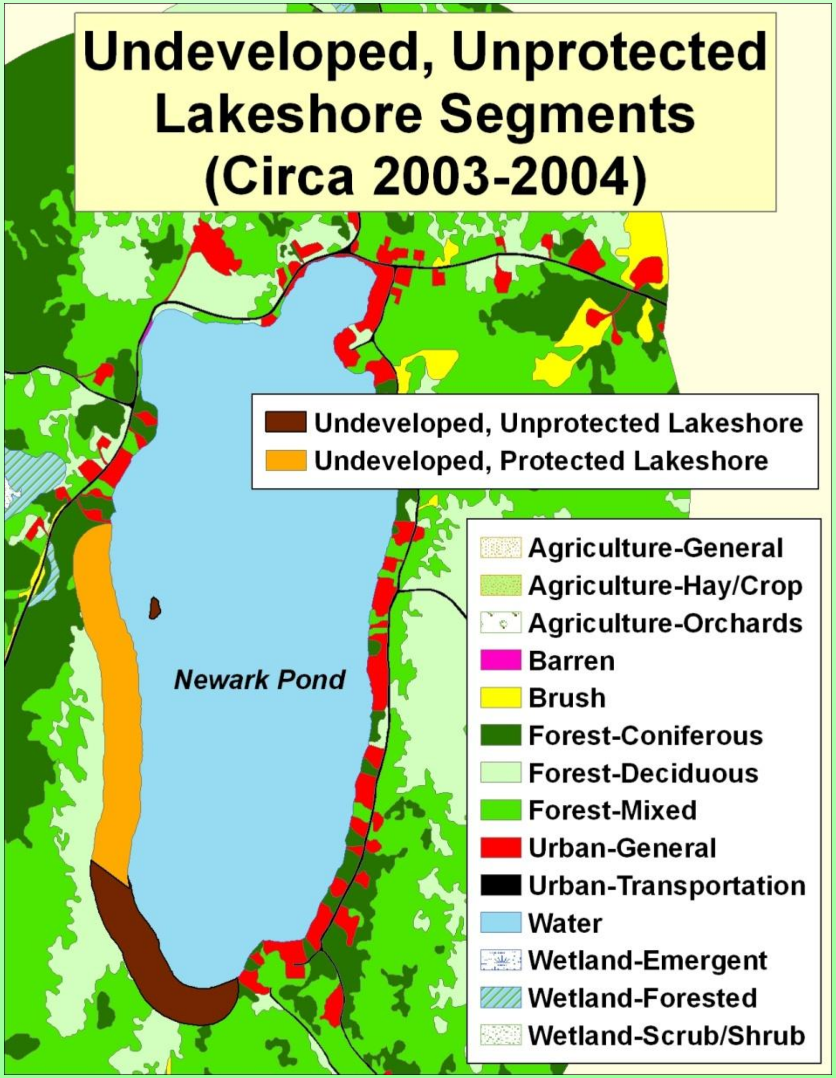
Undeveloped, Unprotected Shorelines: Methods



Undeveloped lakeshore segment on Newark Pond

- All Urban-General (e.g., buildings, lawns) and Urban-Transportation (e.g., roads, railroads) features considered developed
- Created automated script for identifying undeveloped lakeshore segments according to NVDA criteria (at least 1,000-ft long and 250-ft wide)
- Compared undeveloped segments to 2004 Vermont Conserved Lands Database
- Output shows undeveloped, unprotected lakeshore segments (circa 2003-2004)

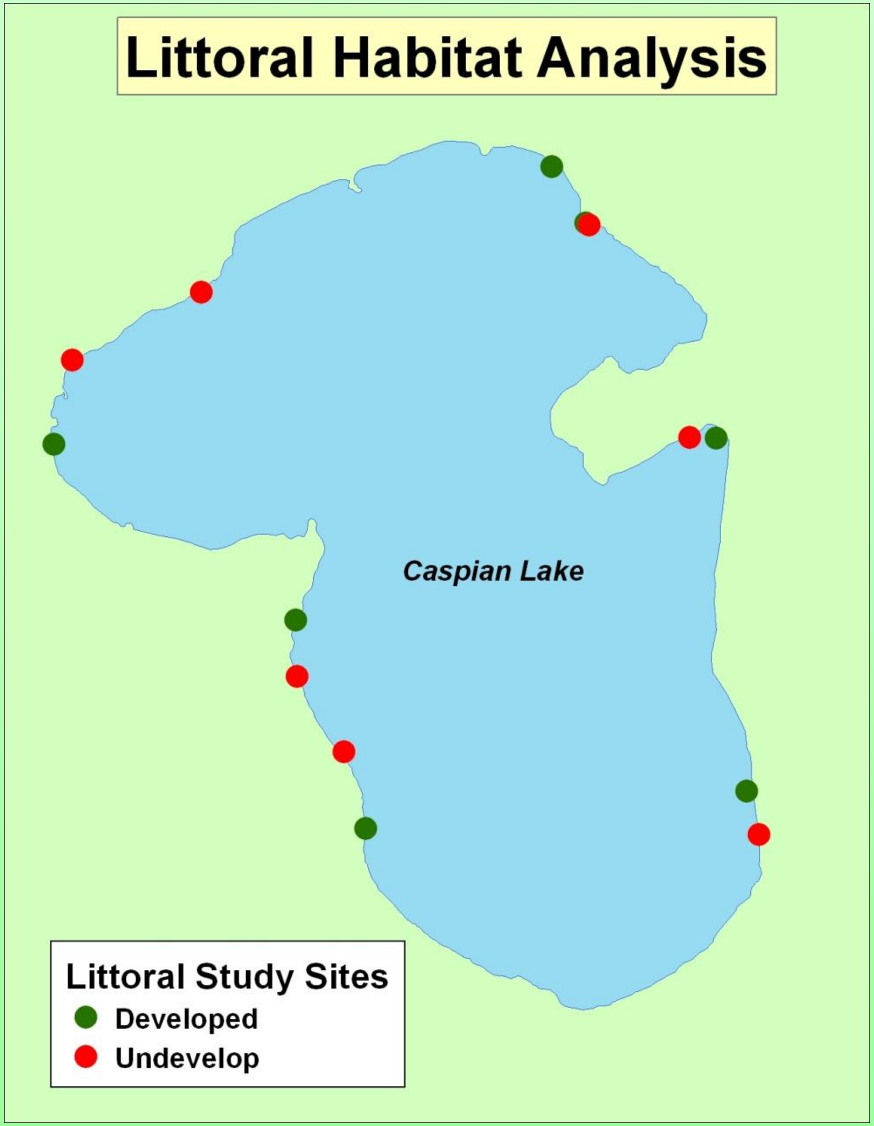
Undeveloped, Unprotected Shorelines: Results



Undeveloped, unprotected lakeshore segment on Newark Pond

- 18 lakes had no undeveloped, unprotected lakeshore segments
- 17 lakes had >70% undeveloped, unprotected lakeshore (as a percentage of the 250-ft buffer around each lake)
- 7 lakes had 100% undeveloped, unprotected lakeshore
- Output GIS layer can be used by public agencies and conservation groups to focus land-protection efforts

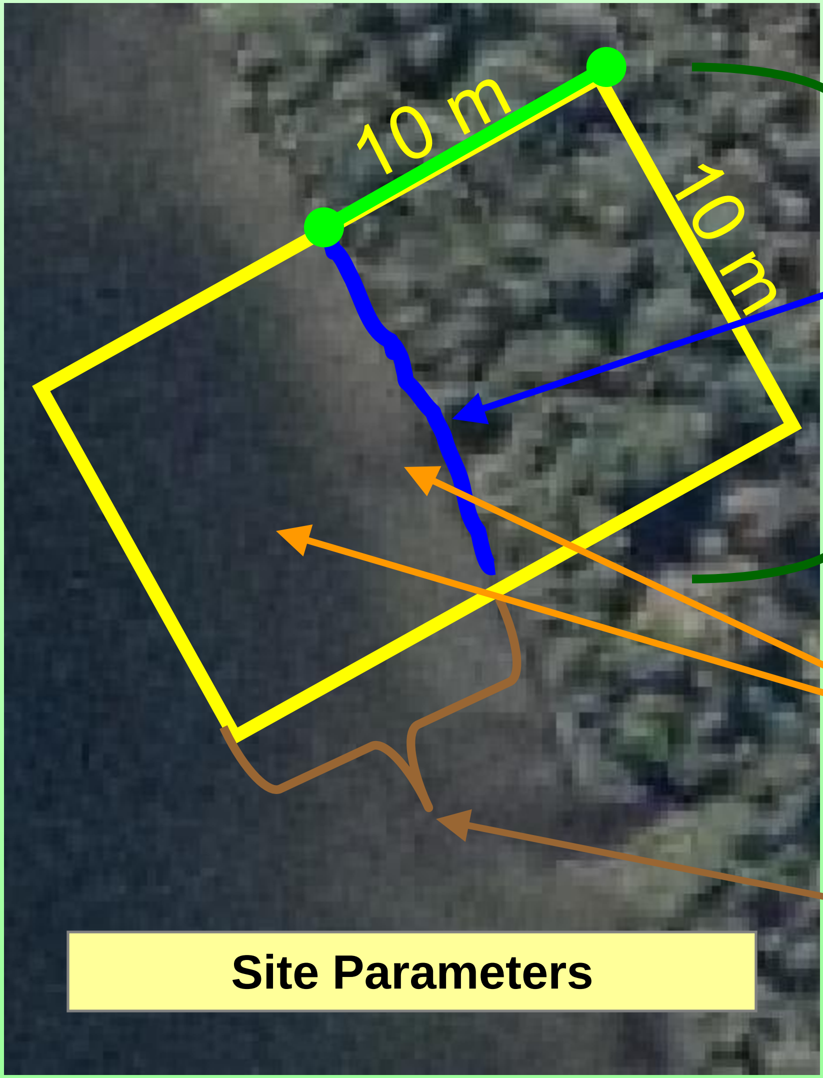
Littoral Habitat Study: Site Selection Methods



Littoral study sites established at Caspian Lake

- Lakes (n = 28) were selected using the following criteria:
  - Range of lake-wide development (0-75% of shore developed)
  - Trophic status: oligotrophic or mesotrophic
  - Well buffered and not sensitive to acid rain
  - Excluded lakes drawn down in winter
  - Small and large lakes
- Paired site design (4-6 developed vs. 4-6 undeveloped)
  - Similar exposure
  - Similar slope
  - Similar sediments
- Selected sites throughout lake

Littoral Habitat Study: Sampling Methods



Sites consisted of 10 x 10 m terrestrial area and 10-m wide littoral area. Deep-water boundary was along 2 m transect, so distance from shore varied according to slope of site

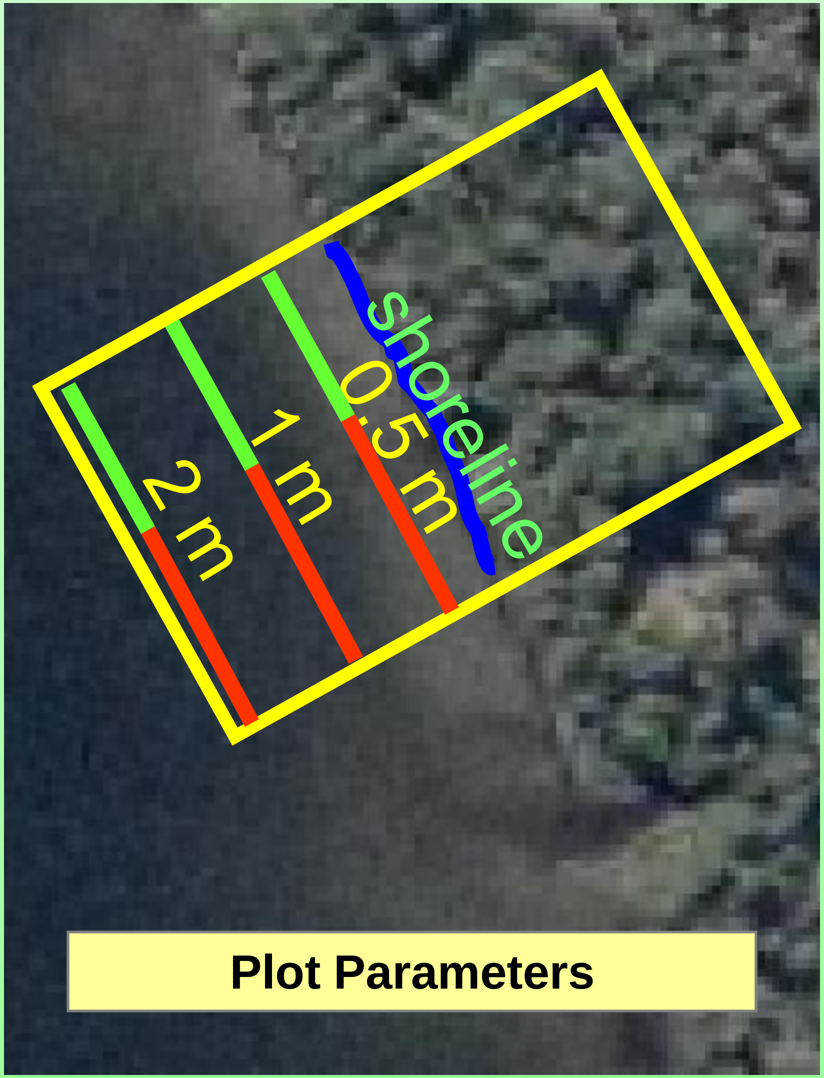
Terrestrial Site Parameters

- **Riparian vegetation along shore**
- **Dominant ground cover in 10m x 10m area**

Littoral Zone Site Parameters

- **Shading measured 1 m & 5 m from shore**
- **Coarse woody habitat (count of submersed trees >10 cm diameter)**

Littoral Habitat Study: Sampling Methods

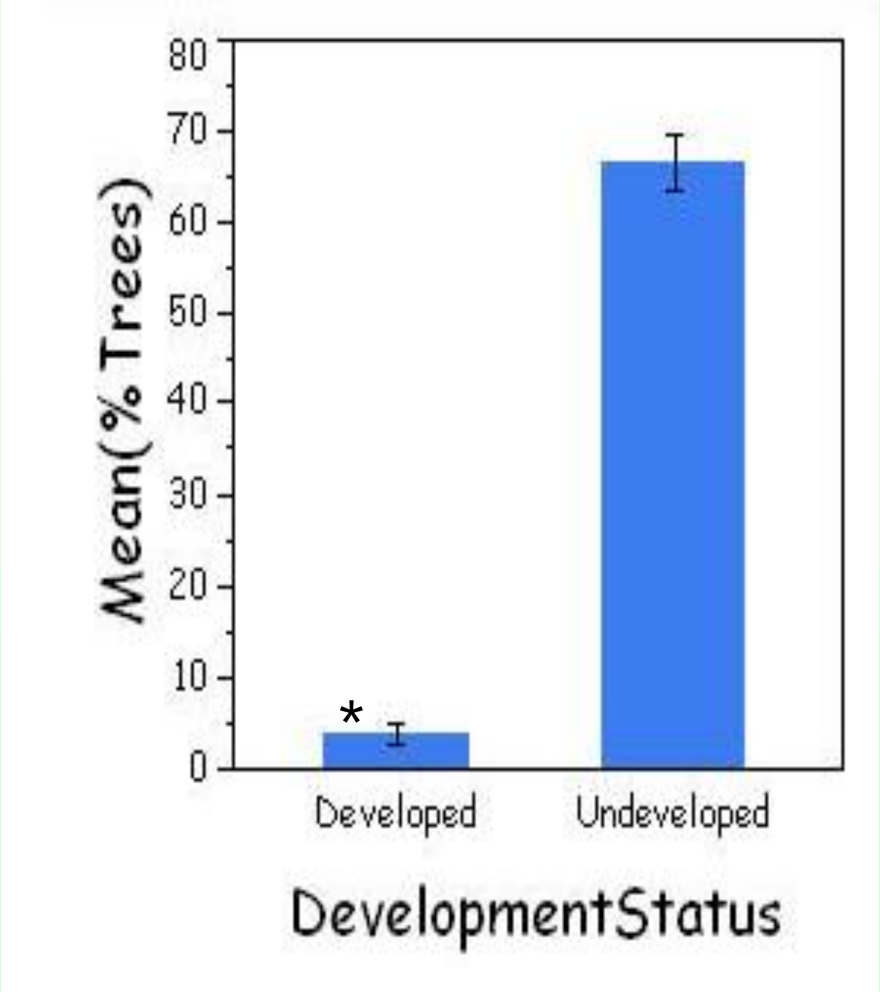


Submersed plots denoted by red and green lines; each plot was 1 m wide and 5 m long

Littoral Zone Plot Parameters

- % Fine (<4-cm diameter) woody habitat
- % Medium (4-10-cm diameter) woody habitat
- % Leaf litter
- % Macrophyte cover
- % Aufwuchs cover
- % Sand
- Sediment % embeddedness

Littoral Habitat Study: Results



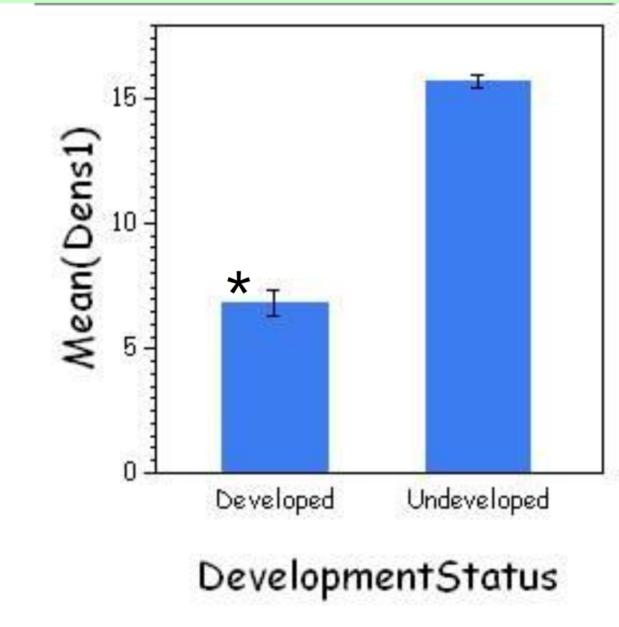
Developed sites had less % tree cover along the shore

Mean +/- SE for percent riparian trees of all sites

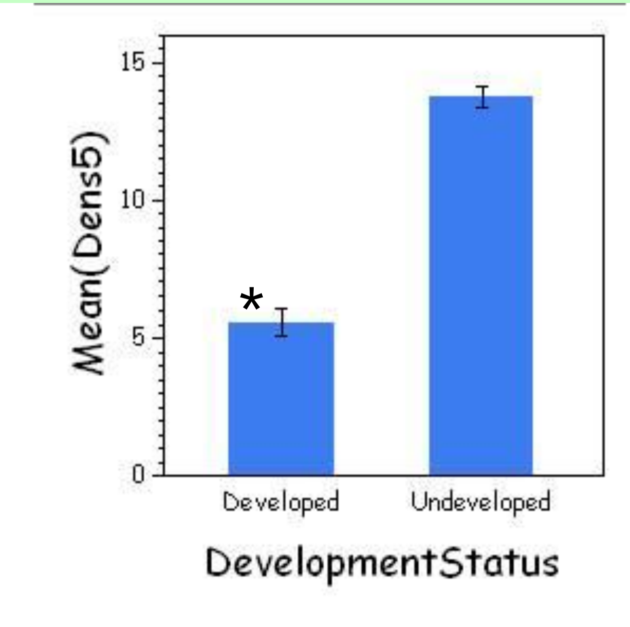
Developed n=122, Undeveloped n=152
Z< 0.0001*
Wilcoxon non-parametric test

Littoral Habitat Study: Results

Developed sites had less shading



1 m from shore



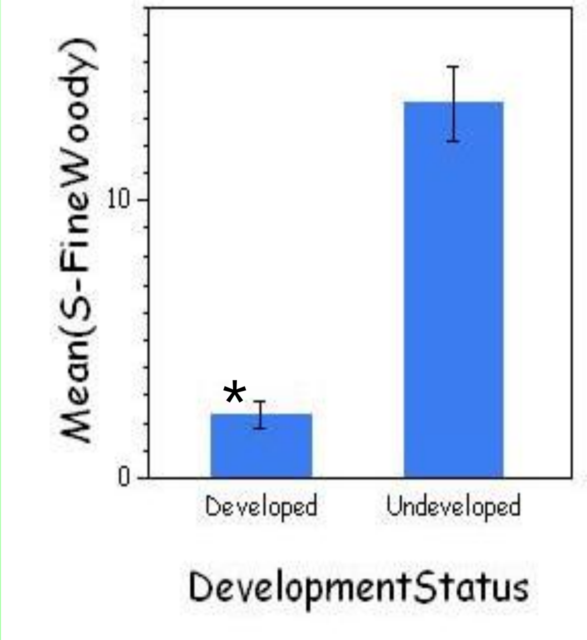
5 m from shore

Mean +/- SE for all sites
Shading measured with a densiometer, where 17 = 100 shading and 0 = no shading

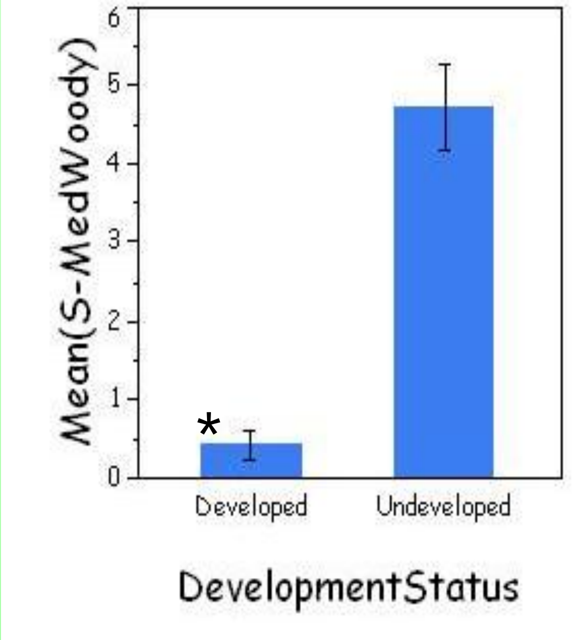
Developed n=123, Undeveloped n=149
Z< 0.0001*
Wilcoxon non-parametric test

Littoral Habitat Study: Results

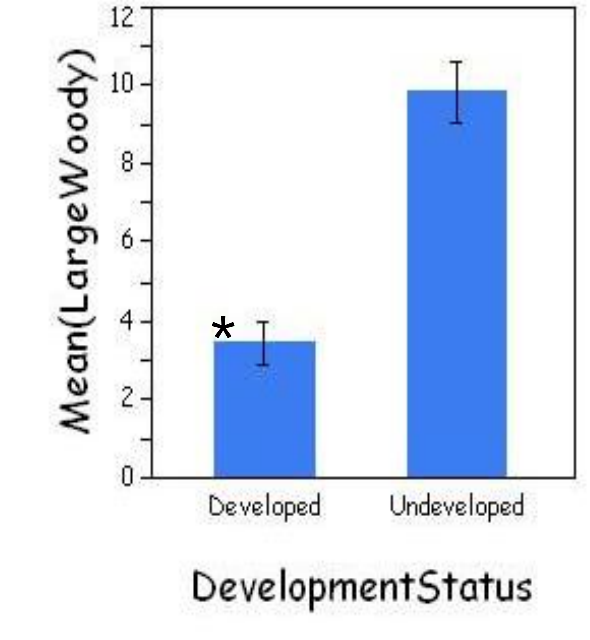
Developed sites had less woody habitat



Fine
(<4cm)



Medium
(4-10 cm)



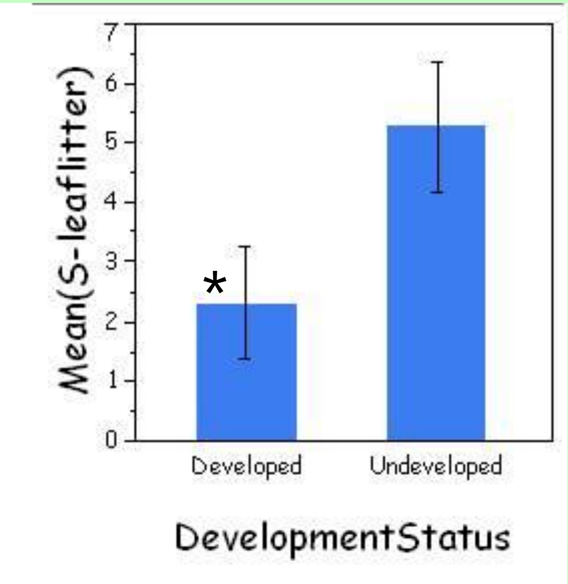
Coarse
(>10 cm)

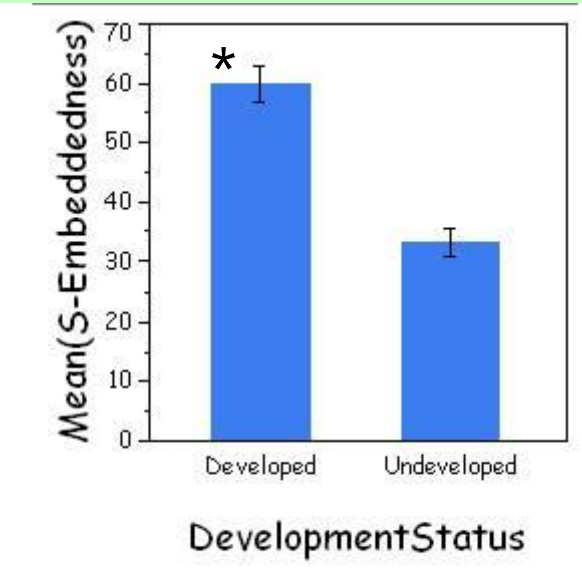
Fine and Medium % cover in plots
(Mean +/- SE for 0.5 m deep transects)
Coarse pieces count
(Mean +/- SE for all sites)

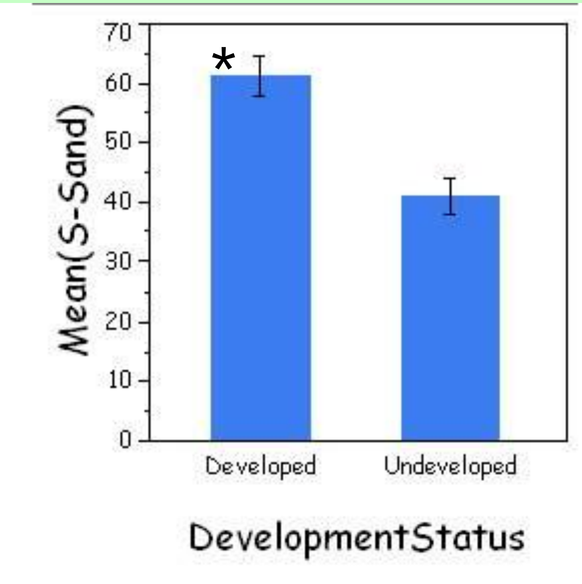
Developed n=123, Undeveloped n=152
Z< 0.0001*
Wilcoxon non-parametric test

Littoral Habitat Study: Results

Developed sites had less macroinvertebrate habitat







Less leaf litter

More embedded sediments

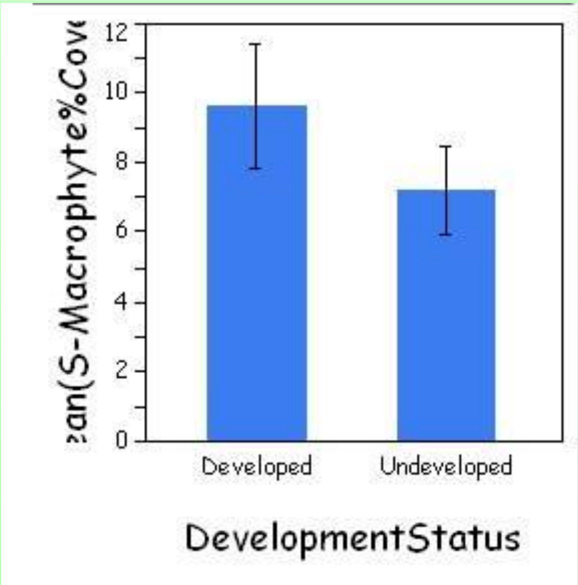
More sand

% cover in plots
(Mean +/- SE for 0.5 m deep transects)

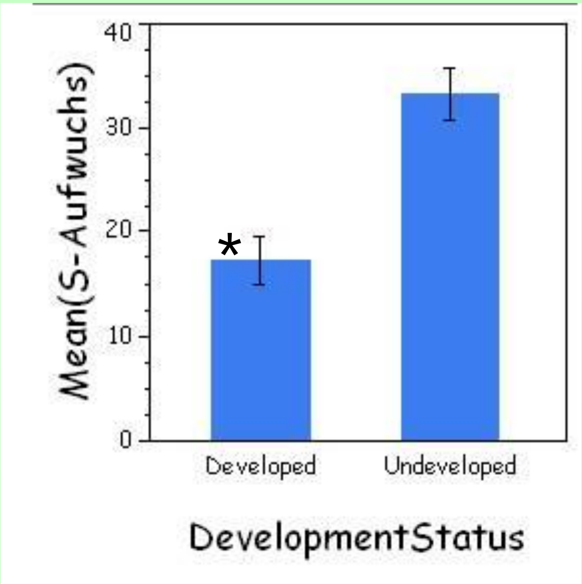
Developed n=123, Undeveloped n=152
Z< 0.0001*
Wilcoxon non-parametric test

Littoral Habitat Study: Results

Developed sites had changes in biota % cover



More aquatic plants

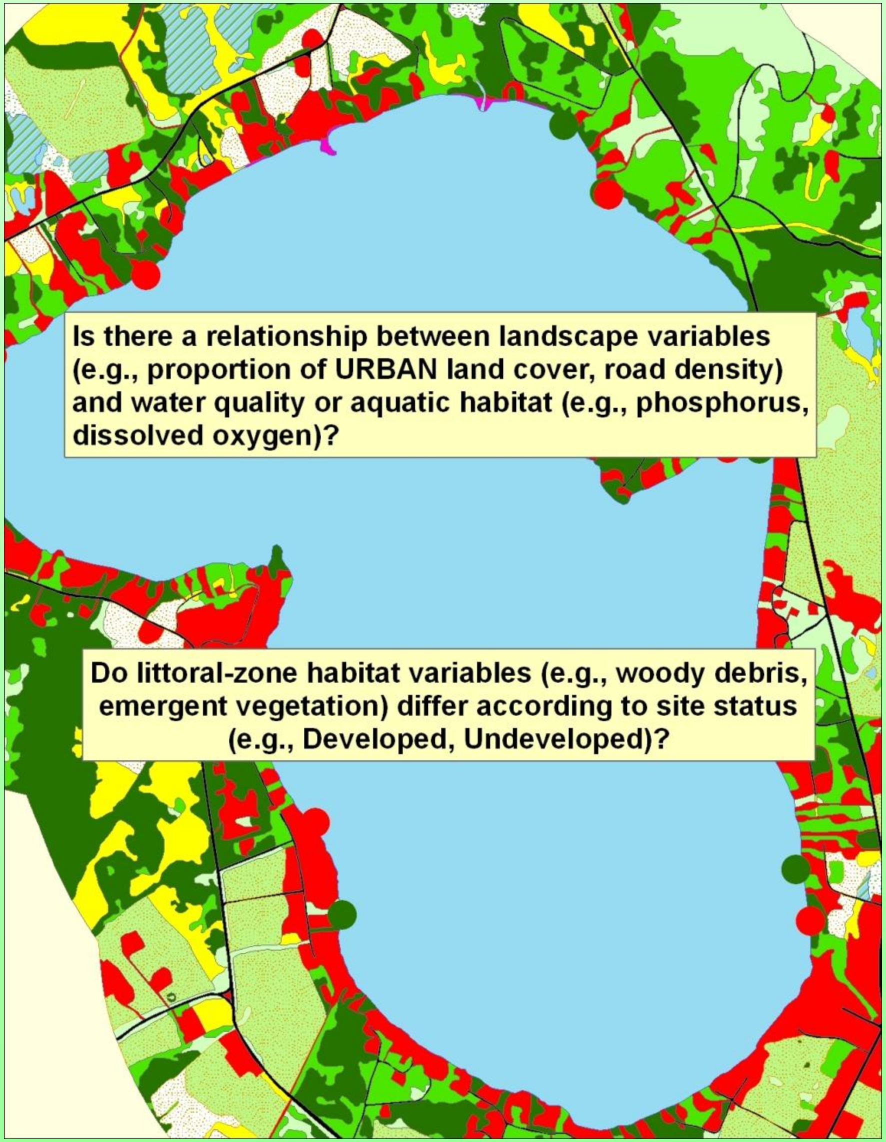


Less aufwuchs

% cover in plots
(Mean +/- SE for 0.5 m deep transects)

Developed n=123, Undeveloped n=152
Z< 0.0001*
Wilcoxon non-parametric test

Statistical Modeling: Methods



- Regression modeling (multiple and logistic)
- Information Theoretic Approach: selected a small number of models *a priori* that were likely to be informative based on preliminary statistical analysis, past research, and expert opinion
- Used Akaike's Information Criterion (AIC) to select best model(s)
- Two levels of analysis: landscape and site
- Landscape-level analysis linked data derived from LULC maps to water-quality and aquatic habitat data for each lake
- Site-level analysis evaluated littoral-zone habitat variables according to site status (Developed vs. Undeveloped) at each sampling location

Statistical Modeling: Results

Presentation and Format of AIC* Modeling Results

- **AIC data presented in table format, with most plausible model listed first**
- **Only plausible models presented in results tables (i.e. models with D_i: values less than 7 or w_i > 0.05)**
  - **More models were evaluated than presented in these tables**
- **Results tables include the following information:**

Model name	Model #	-2log($\mathcal{L}$)	# observations (n)	K	AICc	Δ_i	l_i	w_i

Model name: Parameters used in model
Model #: Number of given model within original model set
-2log($\mathcal{L}$): the -2log likelihood of the model
n: number observations used in the given model
K: number of parameters used in the model (incl. intercept)
AIC_c: Akaike Information Criterion, adjusted for sample size
Δ_i: AIC_c values scaled to the best model.
Values <2 have substantial support, 4-7 have some support, and >10 have no support, given the data and suite of candidate models *
l_i: model likelihood, given the data and candidate set of models
w_i: Akaike weights; normalized l_i scaled to the entire set of candidate models

*** Burnham, K.P. & Anderson, D.R. (2002) Model Selection and Multimodal Inference: a Practical Information-Theoretic Approach. Springer-Verlag, New York.**

Statistical Modeling: Landscape-level Results (Trophic Level)

- Modeled landscape-level data to predict general trophic status of lakes
- Evaluated 24 models
- Model with lake shape and mean width of undeveloped shoreline was selected, indicating that these two variables are the most important in predicting the trophic status of a lake
- Subsequent models with mean basin slope, road density within 15 m of shoreline, and % urban development at gradients along the shoreline were also plausible

Model name	**Model #**	**-2log($\mathcal{L}$)**	**# observations (n)**	**K**	**AICc**	**Δ_i**	**l_i**	**w_i**
Lake shape + mean undeveloped noURBnoAG	24	4.299884	41	3	10.95	0.00	1.00	0.63
slope + rddens15+urb%300	8	5.572396	50	4	14.46	3.51	0.17	0.11
slope + rddens15+urb%600	15	5.836848	50	4	14.73	3.78	0.15	0.10
slope + rddens15+urb%100	7	6.796114	50	4	15.69	4.74	0.09	0.06
slope + shoreurb% + rddens15	6	7.240496	50	4	16.13	5.18	0.07	0.05

Statistical Modeling: Landscape-level Results (Spring Phosphorus)

- Modeled landscape-level data to predict spring phosphorus levels of lakes
- Evaluated 14 models
- As with trophic status (previous slide), lake morphometry (flushing rate and lake shape) and mean width of undeveloped shoreline were the most important variables in predicting spring phosphorus levels
- HOWEVER, subsequent models, including flushing rate with mean slope and varying degrees of urban and agricultural development, were also plausible

Model name	Model #	-2log($\mathcal{L}$)	# observations (n)	K	AICc	Δ_i	l_i	w_i
flushing rate + undeveloped noURBnoAG	14	6.061	41	3	12.71	0.00	1.00	0.36
lake shape + undevelopednoURBnoAG	8	6.708	50	3	13.23	0.52	0.77	0.27
flushing rate + slope + ag15	9	7.607	41	4	16.72	4.01	0.13	0.05
flushing rate + slope + URB300	5	7.753	41	4	16.86	4.15	0.13	0.04
flushing rate + slope + URB15	2	7.852	41	4	16.96	4.25	0.12	0.04
flushing rate + slope + URB100	4	7.889	41	4	17.00	4.29	0.12	0.04
flushing rate + slope + URB30	3	7.903	41	4	17.01	4.31	0.12	0.04
flushing rate + slope + ag 100	10	8.062	41	4	17.17	4.46	0.11	0.04
flushing rate + slope + URB7	1	8.104	41	4	17.22	4.51	0.11	0.04
flushing rate + slope + URB600	6	8.330	41	4	17.44	4.73	0.09	0.03
lake shape + slope + URB30	7	10.371	50	4	19.26	6.55	0.04	0.01
flushing rate + slope + ag 600	11	10.249	41	4	19.36	6.65	0.04	0.01

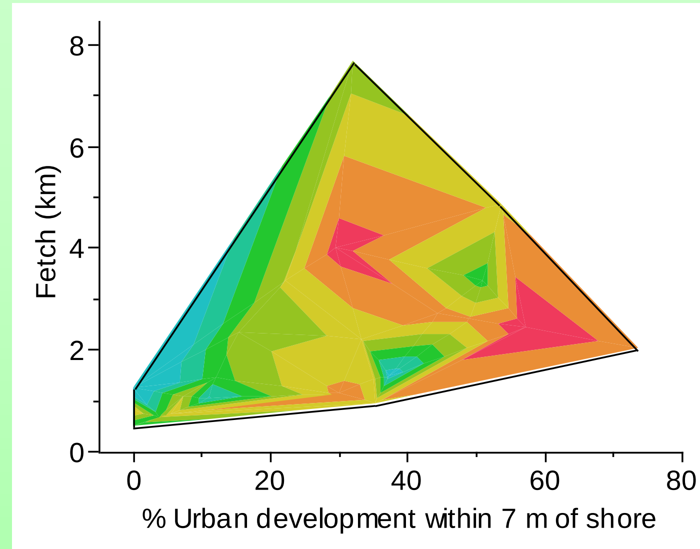
Statistical Modeling: Site-level Results (Coarse Woody Habitat)

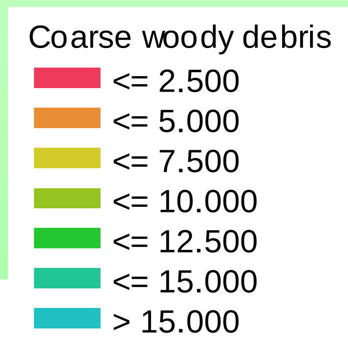
- Modeled shoreline and basin data to predict amount of mean coarse woody habitat in lakes
- Evaluated 12 models
- Model # 12, using lake shape, lake fetch, mean lake depth, and % urban development within 7 m (25 ft) of shoreline, was selected
  - This model had an Akaike weight of 0.81, indicating an 81% probability that it is the closest model to the true model among the candidate models evaluated
- Model # 3, "Basin shape" examined the following variables: fetch, lake shape, mean depth, lake area, and basin area; this model constituted 11% of the weight of the candidate models, and had some plausibility, along with Model # 11 (site slope and % urban development within 7 m of shore)

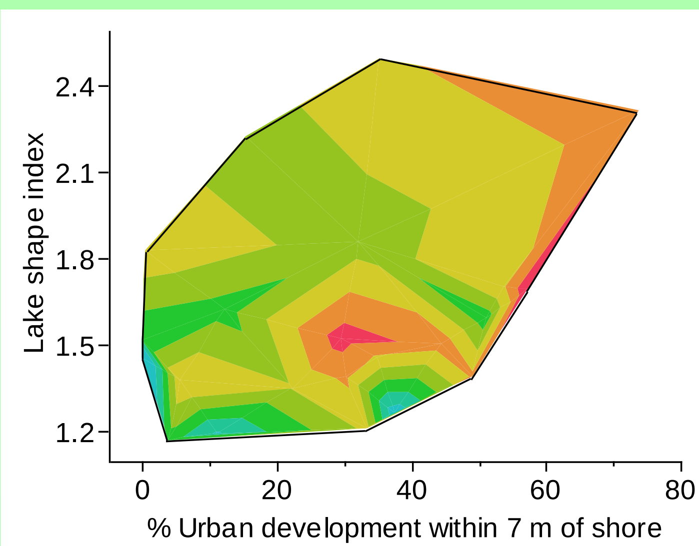
Model name	Model #	-2log($\mathcal{L}$)	# observations (n)	K	AICc	Δ_i	l_i	w_i
Lake shape + fetch + mean depth + urb%7.62	12	4.349	41	5	16.06	0.00	1.00	0.81
Basin shape	3	6.037	49	6	20.04	3.97	0.14	0.11
Site slope + urb%7.62	11	14.260	53	3	20.75	4.69	0.10	0.08

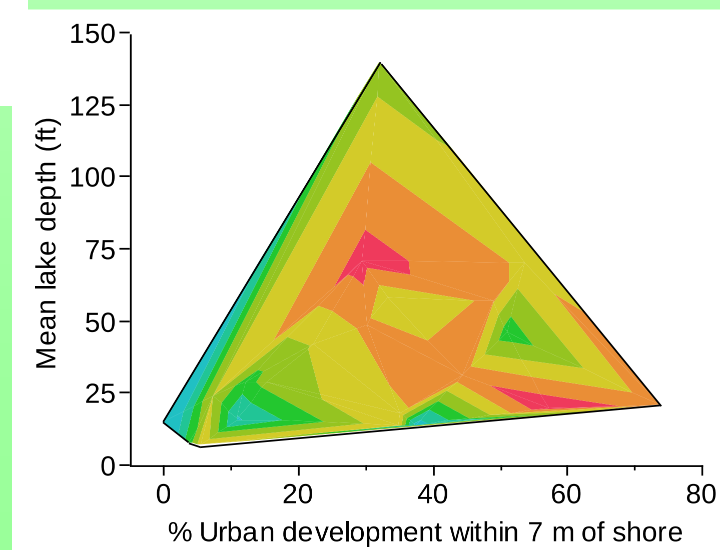
Statistical Modeling: Site-level Results (Coarse Woody Habitat)

- Contour plots illustrate the reduction in coarse woody debris by urban development along gradients with other important physical variables









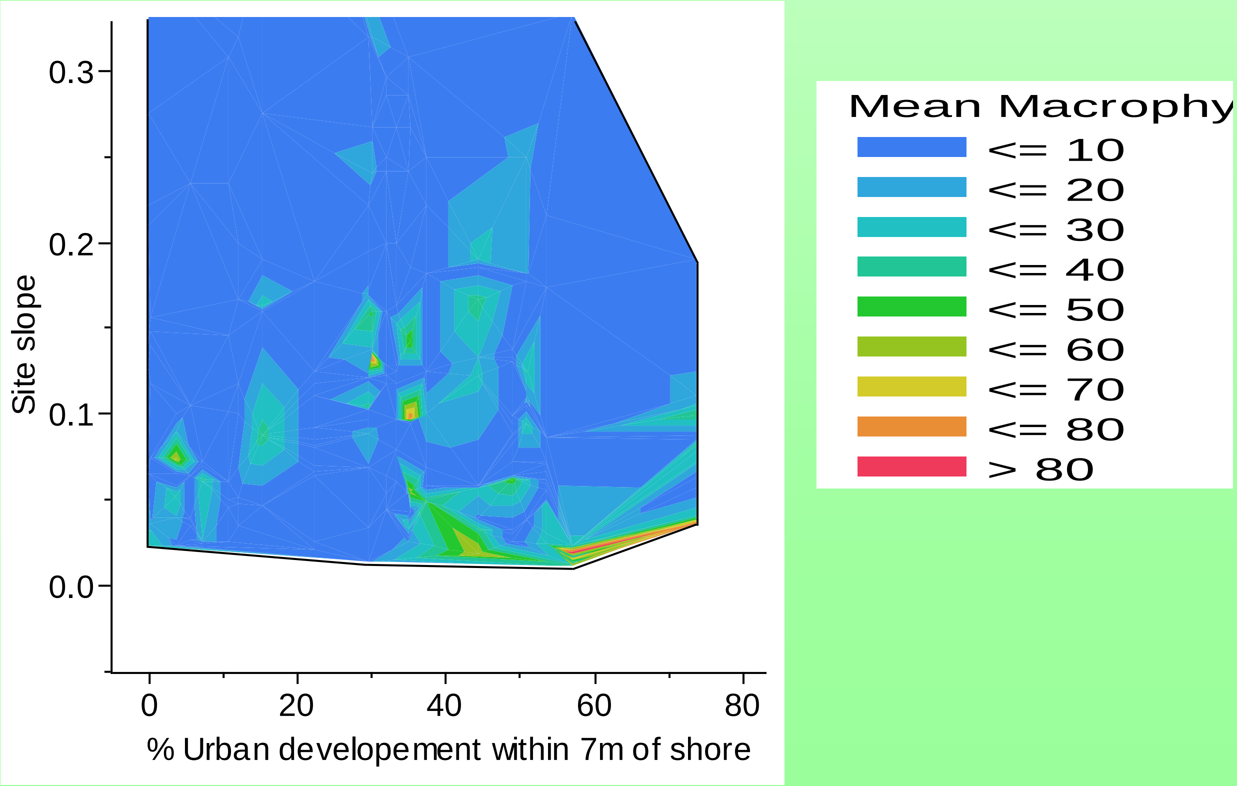
Statistical Modeling: Site-level Results (Aquatic Macrophytes)

- Modeled shoreline shading, site slope, and urban development to predict % cover of aquatic macrophytes within lakes
- Evaluated 17 models
- Model # 12, with site slope and % urban development within 7 m of shoreline, was selected
  - This model had an Akaike weight of 0.67, indicating a 67% probability that it was the closest model to the true model among the candidate models evaluated
- Model # 9, % tree cover and site slope, also had substantial weight (18%); this was most likely due to the fact that % tree cover is negatively correlated with site development

Model name	**Model #**	**-2log($\mathcal{L}$)**	**# observations (n)**	**K**	**AICc**	**Δ_i**	**l_i**	**w_i**
Site slope + URB%7.5	17	7.701	53	3	14.19	0.00	1.00	0.67
% Tree cover + site slope	9	10.352	53	3	16.84	2.65	0.27	0.18
%Tree cover + site slope + lake area	13	10.451	53	4	19.28	5.09	0.08	0.05
% Tree cover + site slope + development status	10	10.521774	53	4	19.36	5.16	0.08	0.05
% Tree cover + site slope + basin area	16	11.875992	53	4	20.71	6.52	0.04	0.03

Statistical Modeling: Site-level Results (Aquatic Macrophytes)

- Contour plots illustrate the increase in % macrophyte cover along a gradient of urban development and slope
- Effect of shoreline development on macrophytes is mitigated with increasing site slope



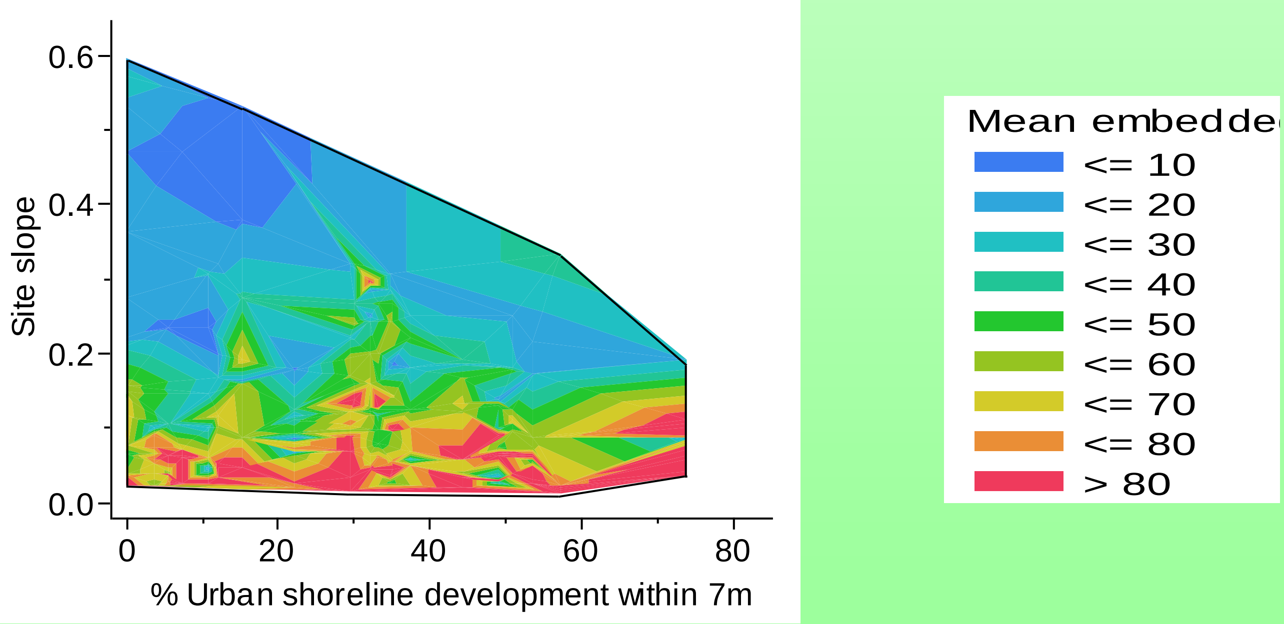
Statistical Modeling: Site-level Results (Sediment Embeddedness)

- Modeled site slope and land use within 25 feet of the shoreline to predict % sediment embeddedness
- Evaluated 14 models
- Model # 4, with site slope and % imperviousness within 25 feet of shoreline, was selected
  - This model had an Akaike weight of 0.65, indicating a 65% probability that this model is the closest model to the true model among candidate models
- Model # 12, site slope and % urban development within 25 feet, also had substantial weight (30%) among the candidate models; this model reflected the urban development around the shoreline, whereas model # 4 reflected all impervious substrates, including urban development and bedrock

Model name	**Model #**	**-2log($\mathcal{L}$)**	**# observations (n)**	**K**	**AICc**	Δ_i	l_i	w_i
Site slope + imperviousness%7	4	27.49	44	3	34.09	0.00	1.00	0.65
Site slope + URB%7	12	29.03	44	3	35.63	1.54	0.46	0.30

Statistical Modeling: Site-level Results (Sediment Embeddedness)

- Contour plots illustrate the increase in % mean lake embeddedness with increases in urban development along shallow-sloped shorelines



Implications and Applications in the Northern Forest Region

- Accurate LULC maps for lakeshore zones are essential for informed conservation planning
- Littoral-habitat characteristics are important additions to environmental-quality datasets for lakes
- At the landscape level, increased volume and intensity of development degrade water quality and aquatic habitat
- At the site level, survey data effectively demonstrate near-shore influences of lakeshore development and site slope on littoral habitat (coarse woody debris, aquatic macrophyte abundance, and sediment embeddedness)
- Findings support the need for lakeshore buffer protections to protect water quality as well as near-shore and aquatic habitat

Future Directions

- Expand LULC mapping to include all lakes > 10 acres (~4 ha) in Vermont's Northern Forest
- Expand collection of littoral habitat data
- Further explore relationship between landscape pattern and water quality using spatial statistics
- Develop algorithm to classify trophic status of lakes based on LULC data
- Improve identification of undeveloped, unprotected lands using updated Vermont Conserved Lands Database
- Use reserve-design concepts to prioritize lakeshores for conservation
- Incorporate Ecosystem Services Valuation (ESV) into lakeshore prioritization

List of Products

- **Graduate Theses:**

  Haselton, B.B. 2008. Systematic conservation planning at multiple scales: protecting terrestrial and aquatic features in a Northern Forest watershed. M.S. Thesis, University of Vermont. Burlington, Vermont. (in preparation)

- **Reports:**

  Howe, E. and Merrell, K. 2007. Lake Seymour littoral habitat summary. Report to Seymour Lake Association. VT DEC

  Merrell, K. and Howe, E. 2007. Summary of VT DEC data relevant to Center Pond lakeshore conservation possibility. Report to Vermont River Conservancy. VT DEC

- **Abstracts**

  NEC-NALMS 2008 Invited talk. Fairlee, VT.

List of Products

- **Presentations:**

Merrell, K., Matthews, L., and Warren, S. 2006. Measuring effects of lakeshore development: A littoral habitat study approach (part I). New England Association of Environmental Biologists, Bethel, ME.

Merrell, K., Matthews, L., and Warren, S. 2006. Measuring effects of lakeshore development: Does lakeshore development affect littoral habitat? (part II). New England Association of Environmental Biologists, Bethel, ME.

Merrell, K., Matthews, L., and Warren, S. 2006. Measuring the effects of lakeshore development on littoral habitat. New England Chapter of the North American Lake Management Society, ME.

Howe, E., Matthews, L., Merrell, K., and Warren, S. 2007. Effect of lakeshore development on oligotrophic lakes in northeastern Vermont. New England Association of Environmental Biologists, Mt. Snow, VT.

Merrell, K. 2007. Summary for graduate class on mediated modeling as part of service learning program at University of Vermont, Burlington, VT.

Merrell, K., Warren, S. 2007. Protecting lake water quality & aquatic habitat from effects of lakeshore development: Testimony to Vermont House of Representatives Fish and Wildlife and Water Resources Committee. Montpelier, VT.

List of Products

- **Presentations (continued):**

Kamman, N., Warren, S., Merrell, K., Copans, B. 2008. The water quality of Lake Seymour. Seymour Lake Association Board of Directors meeting, Morgan, VT.

Merrell, K. 2008. Identification of significant stretches of undeveloped and unprotected lakeshore for conservation initiatives. Vermont River Conservancy, Montpelier, VT.

Merrell, K. 2008. Lakeshore buffers (poster). Display in Vermont statehouse card room. Lake Champlain Committee and Lake Champlain Basin Program day.

Merrell, K. 2008. Significant stretches of undeveloped and unprotected lakeshore in the Northern River Land Trust's focus area. Planning meeting for NRLT, Hardwick, VT.

Merrell, K. 2008. What I do and how I got here. U32 Senior biology class, Montpelier, VT.

Merrell, K., Howe, E., and Warren, S. 2008. Lakeshore development effects on fish and wildlife: A literature review (poster). New England Association of Environmental Biologists, Bartlett, NH.

List of Products

- **Future Publications in Peer-reviewed Journals:**

  Haselton, B.B. In preparation. Systematic conservation planning at multiple scales: Protecting terrestrial and aquatic features in a Northern Forest watershed.

  Merrell et al. In preparation. The effects of riparian development on littoral habitat quality in Vermont lakes.

- **Geographic Datasets:**

  Land-use/Land-cover (LULC) maps for 74 lakes in the Northern Forest of Vermont, March 31, 2008. (To be submitted to the Vermont Center for Geographic Information; www.vcgi.org)

  Undeveloped, unprotected lakeshore segments for 74 lakes in the Northern Forest of Vermont, March 31, 2008. (To be distributed to the Vermont Agency of Natural Resources and its conservation partners; available upon request to other researchers or conservation groups)

List of Products

- **Statistical Datasets:**

  Statistical summaries of LULC characteristics in 74 lakeshore zones; includes all derived landscape variables. (To be distributed to the Vermont Agency of Natural Resources and its conservation partners; available upon request to other researchers or conservation groups)

  Littoral habitat database in VT DEC Water Quality Division. Currently contains site-specific habitat data for more than 25 lakes in Vermont.

- **Complementary Grants:**

  Merrell, K., and D.E. Capen. 2007-2009. Lacustrine riparian habitat protection for SGCN in four Vermont watersheds and three major trophic conditions. Vermont State Wildlife Grants.

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