Ponds of Columbia County: Patterns in their Biodiversity, Thoughts on their Management.

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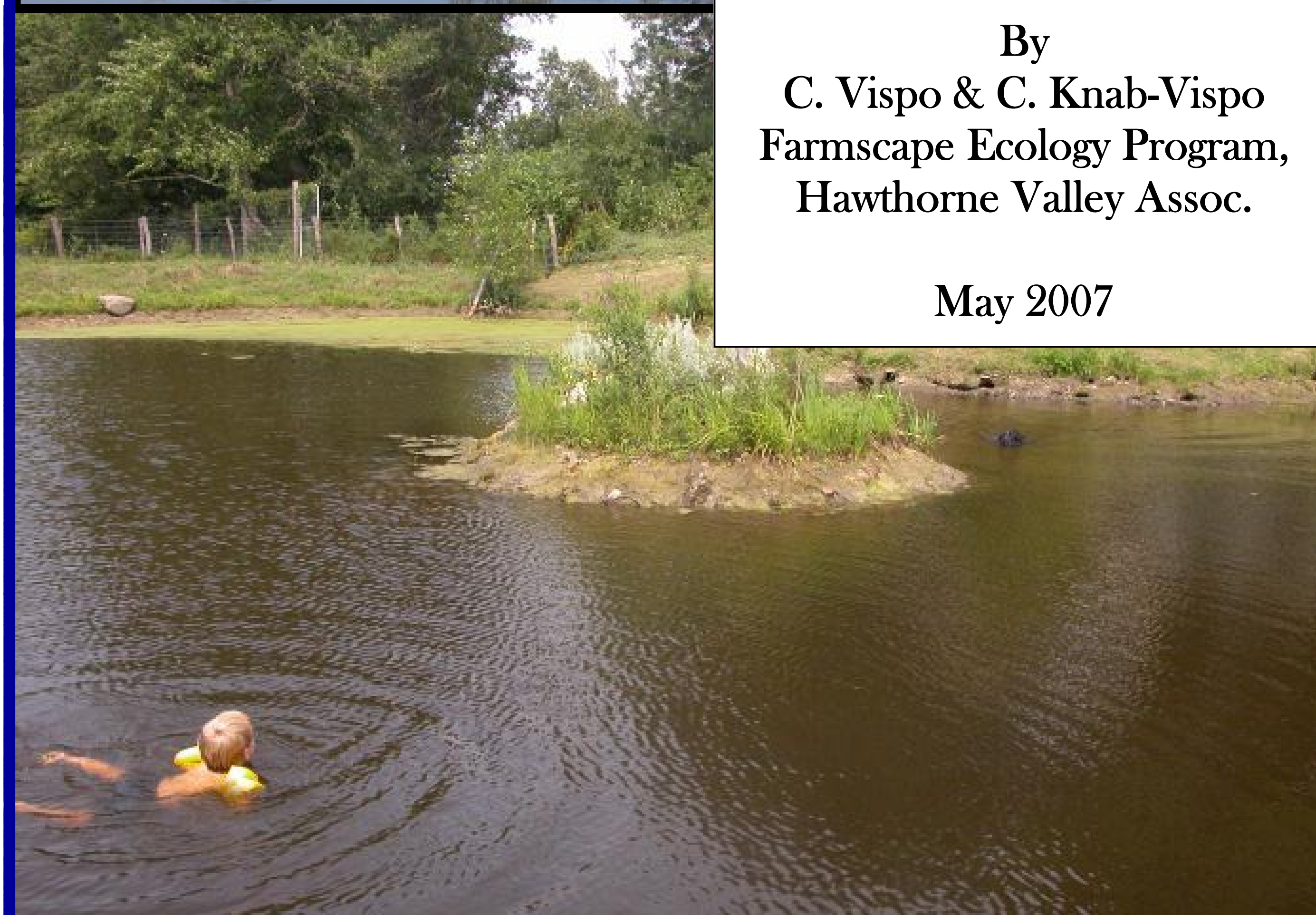

Summary

Here's a dense and dry summary of the next 60 pages. We hope that the text itself is more fun and more understandable than this abridgement, but in case you want to cut to the point...

Ponds have proliferated in Columbia County over the past 50 years. We estimate a 7-10 fold increase during this period. This pattern is reflected nationwide. Initially, agricultural considerations drove their construction; of late, construction has been pushed more by landscaping fashion. Our previous work suggested that farm ponds could provide valuable habitat to some native species. We undertook this work with the goals of better understanding this expanding aquatic habitat, of further exploring ponds as on farm habitats and comparing them with ornamental ponds, and of providing pond owners with greater insight into the ecology of their ponds.

We studied nearly 100 open-land, permanent ponds around the County (although not all data were collected for all ponds). We inventoried pond-associated biota (plants, butterflies, dragonflies and amphibians), measured aspects of the pond physical environment, and gathered remote-sensing data on surrounding landuse. We then took this information and asked how these three different aspects of the pond interacted. How, for example, does land use affect the biology of our ponds, how does it affect their sediments, how does the geology of the pond's setting influence its life? We will emphasize the fact that ponds need to be considered as parts of the greater landscape rather than as isolated worlds to themselves.

Our report is hardly exhaustive and it is entirely descriptive. That means that the patterns we highlight may hint at cause and effect, may be artifacts in our sample, or may reflect deeper relationships that we didn't understand. Nonetheless, to our knowledge, this is the first time that an extensive biological study of our county's ponds has been undertaken. We hope that it provides insight and information for those curious to understand more about their own ponds and those interested in the ecology of our landscape.

In this report, we first explore our information on pond waters and sediments. We collected very limited data on pond water (pH, Total Dissolved Solids [TDS; measured as conductivity], and surface temperature). Most of our ponds were basic or circum-neutral, indicating that buffering of acidic rainfall was occurring. At least in part, this buffering appeared to be due to the presence of calcareous (i.e., calcium-bearing, such as limestone) rocks in our region's geology. Pond pH showed correlations with pond sediment calcium concentrations and with the acidity of the underlying soils as reported by the County soil survey. Total dissolved solids, a measure of the amount of nutrients and other materials in a pond's water, increased in more basic ponds probably due in part to the increased levels of dissolved calcium, magnesium and potassium ions. There was also a suggestion in the data that TDS increased with greater human development in the surroundings. Temperature data were too scant to allow in-depth analyses. In sum, our initial explorations of water characteristics showed a marked link to the geology of the landscape and, perhaps, at least a partial link to neighboring land use.

Our information on sediments was more extensive. Understanding pond sediments is important both because they are historical records of the in-flow of materials to a pond and because they are reserves of nutrients, toxins and other compounds, reserves which biological activity and physical mixing can tap. We had measures of sediment depth, sediment color (basically, darker sediments indicate more organic matter), and the concentrations of several heavy metals (e.g., lead, copper, iron, but not mercury) and potentially important nutrients (i.e., phosphorus and potassium). Pond age appeared to play an important role in shaping sediment depth and color; older ponds tended to have deeper, darker sediments.

The sediment concentrations of a variety of elements (aluminium, copper, iron, lead, manganese, nickel, phosphorus, vanadium and zinc) exceeded presumed background levels in most of our ponds. For several of these elements (iron, lead, managanese, and phosphorus), levels often exceeded values presumed to have ecological effects. We did not, however, find strong evidence of major effects in our subsequent analyses of the biological data. To better understand patterns in our sediment chemistry data, we used a method called principal component analysis to identify clusters of elements that tended to vary together. One important cluster of elements seemed to represent a group of elements showing relatively high levels of con-

tamination or enrichment. This cluster tended to show its highest values in more acidic ponds, with shallower sediments and, perhaps, with more nearby houses. The only other cluster which was readily understandable was one that represented the sediments with relatively high pH's (i.e., "alkaline" or "basic" ponds).

Thus, as we had already seen with water values, sediment chemistry showed apparent links to underlying pond geology and surrounding land use. Sediment color and depth also seemed related to an aspect of pond history (i.e., pond age).

We began our exploration of pond life by looking at indicators of and factors affecting pond *eutrophication*. Eutrophication refers to excessive nutrient enrichment of a pond resulting in unnaturally profuse growth of pond plants and algae. It has been recognized as a major human impact on aquatic ecosystems. One of the common ways that eutrophication is indexed is by measuring chlorophyll levels in the water. (Chlorophyll is the molecule that gives algae and plants their green color.) The index, called the Trophic State Index (TSI), has been used by many ecologists and so lets us understand how our ponds compare to ponds elsewhere. Forty-one percent of the 92 ponds for which we had data were classified as "eutrophic" meaning that their ecologies were likely substantially altered by nutrient in-flow. This compared to 92% of 13 ponds in a study of a more urban Pennsylvania county, and 16% of 24 ponds in a state-wide Massachusetts study.

TSI was not correlated with sediment phosphorus (phosphorus is thought to be one of the main nutrients which causes eutrophication); it was correlated with a variety of land use parameters although their interpretation was not straightforward.

In order to assess pond plant and algal growth more broadly, we also looked at total aquatic growth—a variable we created by combining our September measurements of chlorophyll, spring estimates of algal cover, summer estimates of total coverage of aquatic plants, and September estimates of duckweed/watermeal coverage. Total aquatic growth decreased in the presence of fish and as lawn and woods in the surroundings increased. Sediment phosphorus did not appear to be related to total aquatic growth.

In sum, many of our ponds appeared to be "eutrophied". However eutrophication (measured either as chlorophyll concentrations or as total aquatic growth) was not correlated with sediment phosophurus values. There appeared to be complex relationships with surrounding land use.

After considering eutrophication, we moved on to look at patterns in the diversity of plants and animals. We found 369 species of plants in or around our ponds. Of these, 158 were wetland species, 41 were aquatic, and 170 were upland. We did not look at the factors affecting upland species in any detail, because they were probably not closely related to the presence of the pond. For wetland and aquatic species, we described the factors correlated with the diversity of native and invasive species. Native wetland plant diversity increased as wetland area adjacent to the pond increased and decreased with adjacent development. Native aquatic plant diversity was also enhanced when there was added adjacent wetland and as pond age increased. Wetland and aquatic invasive plant species (an "invasive" species is a non-native species which is rapidly invading certain habitats) showed a strong positive relationship to pH—more basic ponds tended to have more invasives. So again, we see the combined influences of natural geology (as expressed in pH) and land use.

We found 10 species of frogs and salamanders during our pond study. There are more amphibian species in the County, but they were not detected by our methods or favored other habitats. The factor most strongly correlated with amphibian diversity and abundance (we combined these two measures into one) was non-agricultural development. Amphibians declined as such development increased; they increased as total aquatic growth increased.

Vernal pool amphibians (those that favor temporary ponds, Wood Frogs and Spotted Salamanders in our case) increased as adjacent woodland increased. Such a relation is not surprising given that these species pass most of the year not in ponds but rather in the adjacent upland. At least one vernal pool amphibian occurred in 40% of our ponds, despite the fact that all of our ponds were permanent.

Interestingly, when fish were present in ponds, amphibian abundance increased as shoreline vegetation increased; no such pattern was evident when fish were absent. Others have suggested that amphibians rely on such vegetation for shelter from fish predation.

We found 47 species of dragonflies and damselflies during our pond surveys. These odonates have aquatic larvae and so are closely tied to ponds. We divided our odonates into two groups: specialists and generalists. The "specialists" were species which the literature indicated have somewhat restricted habitat preferences, often preferring marshlands or vernal pools as opposed to broad, open ponds. Specialist odonates decreased when fish were present, and increased as surrounding pasture increased. The relationship with pasture, which also appeared in our subsequent analysis of butterflies, appeared to be due to the fact that grazed ponds tended to have scruffier margins than most other ponds. The importance of pH returned in our study of odonates—more basic ponds tended to have more odonate species.

Butterflies are not aquatic during any stage of their lives. However, as caterpillars, some species do rely largely on wetland plants such as sedges. We divided the 39 species of butterflies that we found into two groups—wetland and generalist butterflies. Wetland butterflies were relatively rare and so our analyses were limited. Wetland butterflies increased in abundance as adjacent pastureland increased; we believe that if real, this relationship may be due to the increased wetland area tolerated around ponds in pastures vs. in lawns or developed land. More wetland, meant more caterpillar food plants. We did not explore the factors affecting generalist butterflies in detail because, like upland plants, we presumed they were not closely tied to the ponds. Interestingly, initial data exploration suggested a strong relationship between these butterflies and pond sediment chemistry. It may be that sediment chemistry reflects the chemistry of the surrounding soils to some degree and hence the elements influencing herbivores.

We concluded our work by looking at the intercorrelation amongst our diversity measures: plant, butterfly and odonate diversity all appeared to be quite intercorrelated; amphibian diversity seemed more independent. We created a single measure, "Grand Diversity", which incorporated all four of our diversity measures. Grand Diversity increased with increasing pH and decreased as non-agricultural development in the surroundings increased. Given the correlations associated with each of our diversity components, in which pH and aspects of land use both regularly showed up as important, these results are not surprising. They confirm our impression that the ponds' biotas are shaped by variation in both the natural setting and the surroundings human use.

Our results serve more as background and motive for pond management than as instructions for such. Some agricultural ponds (e.g., pasture ponds) tended to have quite high diversity, while those associated with higher levels of residential or commercial development tended to be poorer. However, it is probably the ramifications of these uses, rather than the uses themselves, that create this pattern. This means that managing your home pond so that it looks more like a pasture pond, even if you don't have cattle, may well have positive effects on biodiversity. Likewise, letting cows into the water trap at a nearby golf-course is unlikely to automatically enhance that pond's biodiversity. Read in depth, we hope our report provides the tools for shaping a vision of the habitat ingredients of relatively diverse ponds. Perhaps this spurs some of you to seek out the resources for then including such ingredients in your own pond management. We provide some management references to get you started!

To request a digital copy of this report, share observations, make corrections, ask questions, or generally shoot the breeze about pond ecology, you can contact us at:

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Introduction

Our landscape has hues, it does not have components in the same sense that a car has components. While its hues can be named and described, they bleed into one another; they are not standardized and discrete. A pond is such a hue. While most ponds have distinct shores where water meets land, much of a pond is not so easily bound – dust settles from the air, water flow brings in the effluent of the surrounding land, organisms creep or fly in and out. Nor are most ponds independent in history – a large majority of our ponds reflect not just water's urge to pool, but also humankind's urge to dig watering spots, fishing holes, fire ponds, reflecting pools and the like.

The point of this little work is to show how the lands that surround a pond meld into the pond itself and how the pond reaches out and into the surrounding history and landscape. Aside from informing our view of the landscape, these linkages have implications for our actions, because much of what affects a pond derives from our own influence on the land.

There is much to know about our ponds and about the landscape and history of our county. This review is patchy and incomplete; we hope that it is nonetheless illustrative.

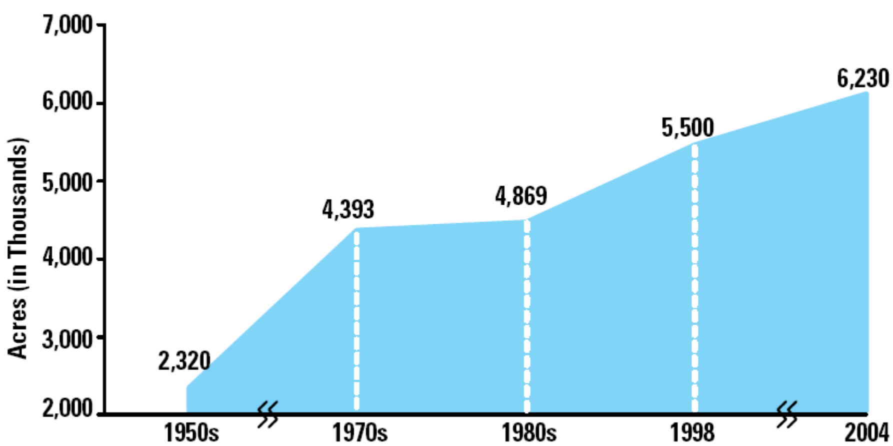

Fig. 1. The history of pond extent in the USA. Taken directly from Dahl 2005.

Why focus on ponds? Because they are something new and different, literally.

Ponds are the most rapidly growing of our aquatic habitats; indeed, they are probably the only class of still-water wetland that is not declining nationally and regionally (see Fig. 1). The latest national assessment of wetlands announced that for the first time in the past 200 years, wetland area increased in the US. Although rates of decline for other types of wetlands have moderated, the sole reason for this *increase* was the increase in

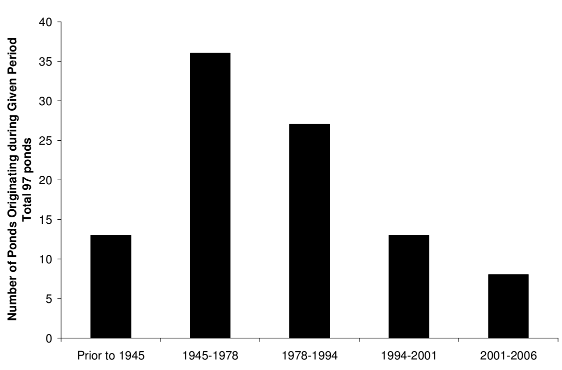

Fig. 2 Columbia County pond construction during differing time periods, based on our sample of 97 ponds.

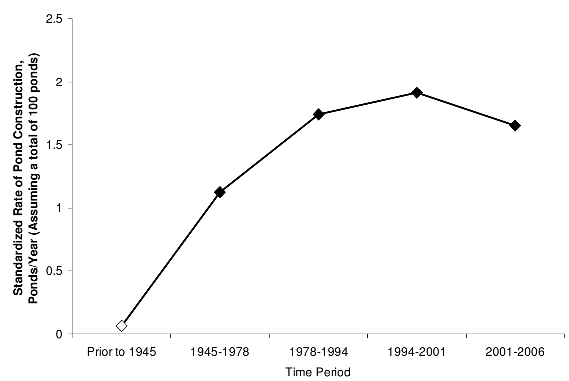

Fig. 3 Estimated rates of pond construction (ponds built per year) rates are calculated for a hypothetical sample of 100 extant ponds.

pond construction. In local terms, when we used aerial photos to count ponds in a square mile around one Columbia County Farm, we found an increase from 2 ponds in 1948 to 24 ponds in 2004. Of the 97 ponds we aged (using historical aerial photos), only 13 were present when the first set of photos was taken in the 1940s (Fig. 2). The rate of subsequent pond construction has been high (Fig. 3). This pond-building flurry has much to

Fig. 4. A new pond under construction. While ponds can add beauty, recreation potential and a source of water in case of fire, it is worth asking of any new pond—what wetland habitat might it be replacing? And, will the pond that results have ecological value for native species?

do with the recent history of our landscape.

In the 1960s and '70s, the US government subsidized extensive farm pond construction. Farmers took advantage of these monies to build ponds for livestock watering, irrigation, and run-off control. After that period, agricultural and residential purposes were both important, with the residential probably dominating during the past 5 – 10 years. Reportedly, on-site fire ponds ease insurance costs, however, much of the momentum comes from fashion – a pond has become a desired component of a rural property. The landscaping of corporate and private properties now frequently includes the installation of a pond. This rapid proliferation of ponds (Fig. 4) prompts our investigation of their role as aquatic habitats. Are all these ponds providing valuable aquatic habitat? Or, as the author of the latest national wetland assessment poses the problem,

> *Without the increased pond acreage, wetland gains would not have surpassed wetland losses during the timeframe of this study. Although increases in pond acreage were important in meeting the national wetland quantity goals, creation of some types of ponds may not meet the national wetland quality goals established in 2004. Ponds created as mitigation for the loss of some vegetated wetland types are not an equivalent replacement for those wetlands. Gauging the functional value of ponds and predicting their long term viability will require additional work.* [1]

Our previous work provided additional justification for our focus on ponds. Our initial studies of farm ponds indicated that some ponds were utilized by amphibians, including vernal pool species. Researchers in other areas have also concluded that some farm ponds can provide valuable amphibian habitat. We were intrigued and decided to continue our exploration of the biodiversity of on-farm habitats by focusing on ponds and trying to better understand their conservation value for native organisms. As a point of comparison and because of their rapid proliferation, we also looked at ornamental ponds in residential or commercial areas.[2]

Finally, and related to the first point, the public is interested in ponds. Our public displays during the summer months frequently result in questions about ponds or their inhabitants. Often these are management questions such as "My pond is green, what do I do?". While it might seem a stretch, this is really an ecological question, and the answer may have as much to do with ecological outreach as it does with providing active management solutions. (To paraphrase Winfield Fairchild, a pond ecologist, one needs to show people that 'green is beautiful'.)[3]

After reading the report that follows, we hope that you will better appreciate the interconnectedness of our landscape, the rich ecology of your ponds, and your role in maintaining that ecology.

A Warning

The descriptions that follow rely heavily on graphs and some pseudo-statistical analyses. While we have done our best to tie these numbers to reality, there are tables and graphs nonetheless. We believe that these details are important for 'truth in reporting' – how can you, or anyone else, make reasoned judgments concerning land use if you do not have access to basic data and analyses? Without those data, you would just have to trust us and, take it from us, that's a risky proposition! So, please do not be deterred if you see lots of numbers and figures – they are just numeric ways of describing observations. If you explore them enough, you will surely come to question some of our conclusions, because what we present are only considerations of evidence not absolute truths. If you come to a reasoned disagreement with some of our conclusions we'll be happy, not because we like to be wrong, but because it would show that you've really dug in.

Statistics are a way of summarizing numbers and asking how likely a given result is by chance alone. In order to do this with 100% validity, one's data has to meet certain assumptions. Our data doesn't always do this for reasons that will be mentioned later. Thus, the statistical results that we cite should be seen as indicators of patterns and their relative strength rather than as rigorous tests of statistical significance. Furthermore, while our interest in correlations and comparisons derives from an interest in possible cause and affect, these correlations alone only indicate that two (or more) variables vary in similar ways; conclusions about cause and effect can only be made based on background information and, ultimately, are best tested through experimentation when possible. Finally, probability alone tells us that some of the apparent relationships highlighted by our statistical analyses are likely due to happenstance and don't reflect broader ecological patterns.

Ponds are focal points for human influence on the landscape; they proliferated rapidly during the past century. Based on our study of Columbia County ponds, this paper will illustrate the connection between ponds and the surrounding landscape, and evaluate aspects of their ecological role. The statistics that we present are meant to illustrate possible patterns in the data rather than provide rigorous statistical tests or direct proof of cause and effect.

Part I: The Pond Itself

The Ponds We Studied

We studied 97 open ponds scattered across Columbia County (Fig. 5). We intentionally avoided including ponds surrounded by forest. We may include these at a future date, however because of our limited person-power and the fact that our questions related primarily to open ponds in altered landscapes, we did not include entirely forested ponds in a semi-wild state. Our ponds did vary widely in their proximity to forest and the degree of development in their surroundings. We chose ponds so as to cover a range of common land uses in our area. Based upon surrounding land use, we classified 34 of our ponds as farm ponds, 28 as lawn ponds, 25 as having mixed uses, and 10 as no longer having either use (but yet still located in open areas).

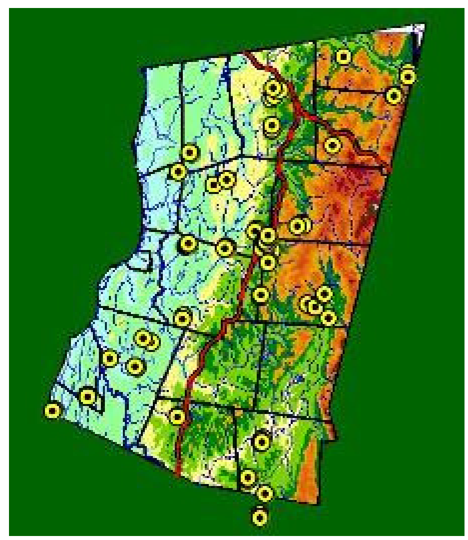

Fig. 5. The location of the ponds we studied. Three ponds were, technically, located in Dutchess County, however they belonged to Columbia County farms.

We tried to distribute our ponds across the County, however the practicalities of gaining access to private property and the logistics of travel dictated by our budget, meant that our ponds were not randomly distributed on the landscape. A random distribution is one assumption in

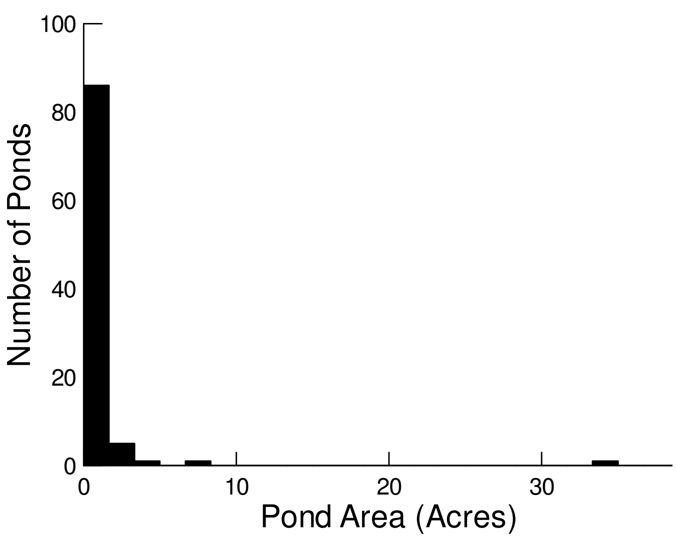

Fig. 6. The size distribution of all the ponds we studied; most ponds were less than 5 acres in size.

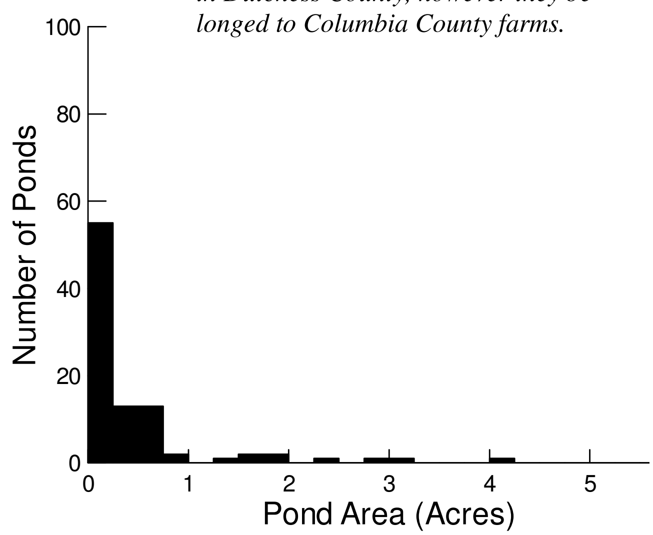

Fig. 7. The size distribution of the smaller ponds (< 5 acres) that we studied.

Fig. 8. Our ponds ranged from constructed garden ponds to...

some statistical tests. The average pond size was .9 acres, although most ponds were clustered below 1 acre (Fig. 6). The average size of the 91 ponds of less than 1 acre in size was about 1/4 acre (Fig. 7). Figs. 8, 9, 11 and 12 illustrate some of the variation in size and location found amongst our ponds.

We were not able to gather all data from all ponds. Hence, in the figures, tables, and summaries that follow, the total number of ponds included in our analyses will vary somewhat depending upon exactly which measurements we are considering.

The Broth and the Dregs

One can think of the pond as having two aspects: its waters and its sediments. In other words, what you swim through and the muck you step into. Before considering what lives in or around a pond, let's consider some of the characteristics of a pond's water and sediments.

Aside from the waters draining highly eroded areas of the world, such as the ancient rocks of the Adirondacks or Guyanan Shields, few natural waters are very pure. (And even these waters have been tainted by human activities.) Most waters are a soup of sorts, albeit an admittedly watery broth. They may contain nutrients, toxins and other chemicals which influence the life of resident organisms. Like the sediments that collect in the bottom of your soup bowl, the sediments of a pond are mostly the accumulated debris that have filtered down out of the water above.

Sediments (Fig. 10), like the waters they underlie, may contain various foods, poisons and other materials. However, these chemicals are not sealed in the pond's basin. The surface sediments are easily churned up and resuspended in the water by wind, fish, wading cattle or other disturbances. Furthermore, sediment-dwelling creatures may consume foods in their mileau and then be consumed by animals living in the water. Likewise, a plants' roots may dig into the mire and carry sediment chemicals up into their exposed greenery. It is because of this continual potential for interchange that hazardous material remediation

Fig. 9. …. farm ponds and ….

Fig. 10. An example of a pond core. The clear plastic tube was held within a metal tube that was lowered into the sediment. It was then capped, returned to the surface, and removed from the metal case.

often considers removing or sealing aquatic sediments. Remediation sometimes also uses plants to extract unwanted soil elements.[4]

Fig. 11. ...to ponds in more manicured surroundings through...

There are many ways of describing a pond's waters. One could, for example, analyze for just about any kind of element or compound. However, many of these tests are costly and might not tell us much that's relevant to a pond's life. While we would have liked to do more, we measured only three different characteristics of each pond's waters: its pH, its temperature, and its dissolved solids.

The pH of a pond tells you its acidity. As the troubles with acid rain illustrate, pH can play an important role in determining what lives in a given pond. Acidic vinegar is used as a preservative because relatively few creatures can live in it. The pH also has a more subtle effect. In general, higher pH's (i.e., less acidic ones), tend to liberate more usable nutrients. This is one of the reasons that farmers lime their fields. Lime, by increasing pH, makes soil nutrients more accessible to growing crops. However, too high a pH can also stress plants. Pond pH is determined by the interaction of acid inputs and a pond's buffering capacity. If a pond is sitting on a giant Alka-Seltzer tablet, then that next hot chili that falls from the sky won't be as troubling. Calcareous rock is the geological equivalent of the Alka-Seltzer tablet. (Rocks or soils bearing limestone or related materials are called "calcareous" because of their calcium content.)[5]

Total dissolved solids (often abbreviated TDS) is a measure of the thickness of a pond's watery broth. It gives a crude index of how much material is dissolved in the water. It doesn't tell you what that material is, but it does give you one way of indexing relative purity. (Of course, life needs minerals and nutrients to survive, so don't equate purity with vitality.)

Temperature is one of the great pace makers of nature. The speed of most reactions – living or mineral – increase as temperature increases. In our case, because temperature varied relatively little, because it reflected a variety of factors (e.g., exposure to sunlight, recent weather, presence of springs), and because our measurements were very scant (one measurement from the pond's surface), our measurements probably have limited utility, but we'll mention them so as to make a broader general point about pond ecology.

Fig. 12. ...what might be more suitably described as a small lake.

Our information about pond sediments was more extensive. First of all, we wanted to know about sediment phosphorus levels. Phosphorus is thought to play a key role in pond ecology because, although it is necessary for the growth of most plants and algae, it is not usually common in nature. This means that it is frequently a "limiting nutrient". Just as water might be a limiting nutrient for an explorer in a desert, but food a limitation for a sailor becalmed on the Great Lakes, so too do ecologists often highlight certain nutrients as the determinants of life's exuberance in a given environment. In ponds, phosphorus is one such keystone. Thus, we tested for phosphorus in our pond sediments. We also collected information on the concentrations of a range of other elements, including several heavy metals.

Aside from describing a sediment's chemistry, we also described a couple of its physical qualities, namely its minimum depth and its color. Sediment depth was measured by noting the length of the sediment column that our corer brought to the surface. Because that corer had a limited capacity and because sediment was sometimes lost during collection, we believe our measurements indicated a minimum depth. Organic matter (mainly carbon – think charcoal) tends to be black, and it could be indexed by recording the color of our cores. We described color as light, medium, and dark with the last reflecting sediments with the deep black of organic matter and the first those with the clayey grey of mineral sediments.

What do these measurements tell us about the ambience of our ponds? Here comes the data…

We studied 97 open ponds scattered around the County. These averaged a bit less than 1 acre in area. One can partition ponds into a water and sediment portion, the broth and the dregs, so to speak. We'll begin by looking at each of these separately before looking at in-pond life.

WATER

pH – the Facilitator: Low pH (high acidity) can render a pond lifeless. While there are natural sources of acidity, the recent acidification of northeastern waterbodies is mainly due to acid rain, which, in turn, is caused mainly by the sulfur and nitrogen released by fossil fuel burning. However, just because the rain has a pH of, say, 4.5, doesn't mean all waters receiving that rain will have a similar pH. Luckily, there is a range of factors that help buffer a pond's acidity, and some of these are effective in our area. Ponds without such buffers can suffer profound ecological effects.

Our waters are not very acidic (Fig. 13). A pH of 7.0 indicates neutral waters, and most of our ponds were above that value. The average, for 90 ponds, was 7.4. This compares to an average of 5.6 for 56 Adirondack ponds. Given that 6.0 or lower is the pH of most rainwater, our ponds were likely buffered by alkaline soils (or bedrock) or by agricultural liming. Calcium-containing rocks and soils are the most common regional geologic buffers and, indeed, the presence of calcium in our pond sediments was significantly related to pond pH (Fig. 14). Based upon data in the Columbia County Soil Survey (as summarized by Hudsonia), we classified each pond's underlaying soil type as Calcareous (C), Slightly Calcareous (SC), or Not Calcareous (NC). Appropriately enough, pond sediment calcium was related to this classification of the underlying soil (Fig. 15); it was not, however, related to pond use (Fig. 16). This suggests that the pH of our ponds may have been determined to a large degree by the underlying minerals, rather than by the surrounding land use.[6]

In conclusion, pH did not seem to reach ecologically poisonous extremes in our ponds. However, pH

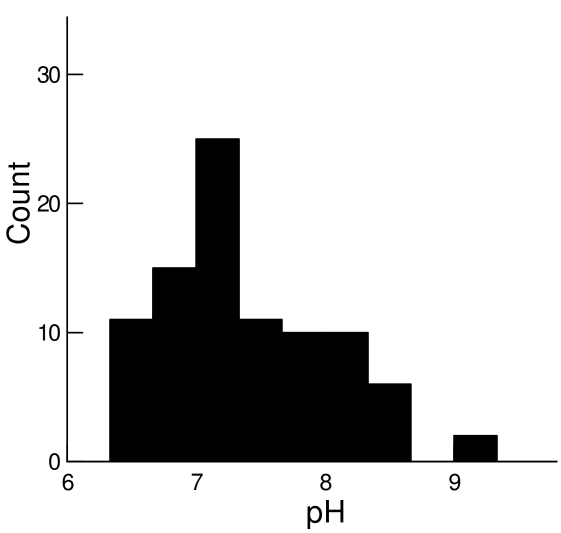

Fig. 13. The pH of our ponds. Seven is considered neutral; most of our ponds were basic (i.e. above 7).

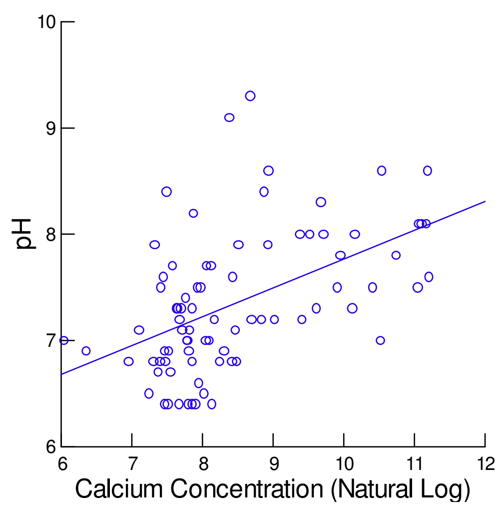

Fig.14. The relationship between sediment calcium concentrations and water pH. Sediment calcium is determined largely by the nature of the geological context.

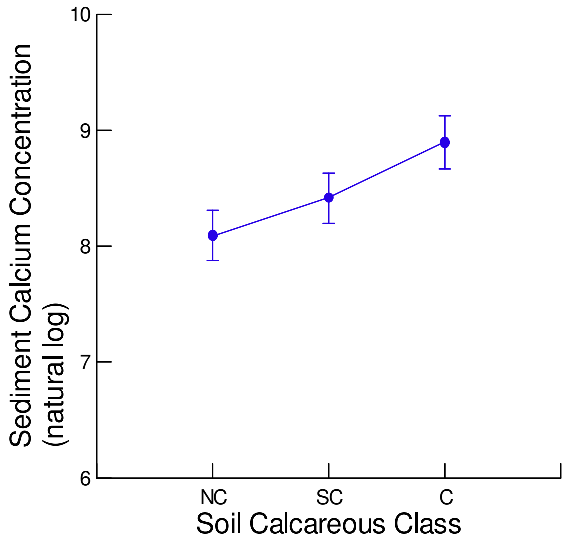

Fig.15. Calcium content of pond sediments compared to nominal calcareous class of underlining soils (NC = not calcareous; SC = somewhat calcareous; C= calcareous. This type of graph is used for categorical variables—the center point above each category indicates the mean value of, in this case, sediment calcium. The capped lines above and below each point are an estimate of likely variation in the given mean.

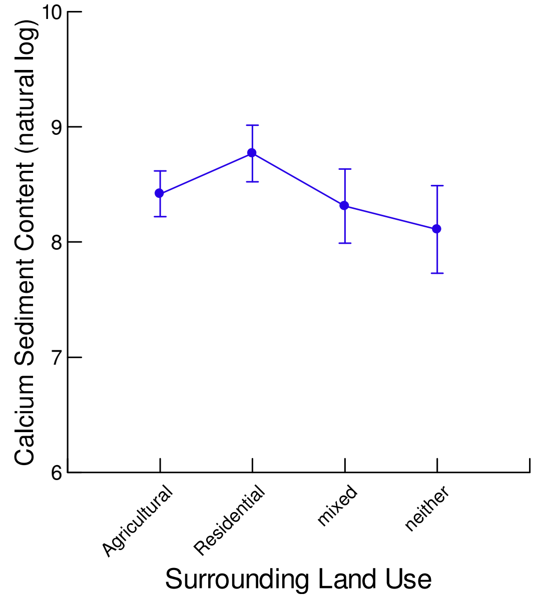

Fig.16..Calcium sediment compared to surrounding land use. There was no indication that calcium was derived predominantly from liming on adjacent farmland.

also has more subtle effects, and we shall see later that pH was correlated with some aspects of our ponds' ecologies. We are already beginning to see how it is important to consider the pond in its broader context – a pond's bedding, formed by our complex geological history, can affect its chemistry and hence its biology. The calcareous rocks that buffered our ponds are the lithified remains of sea organisms from millions of years ago.[7]

<u>Temperature and The Energy Ambience:</u> Sunlight is the primary cause of water warming in most of our ponds, and our temperature readings hint at the fact that pond life tends to receive more solar energy than that in our streams. For example, the water temperature of three Hawthorne Valley ponds measured in April was 63 °F, whereas that of a stream on the same property, but measured at an even later season (in May of the previous year) was about 50 °F. These results are hardly surprising, most of us know that a dip in a stream is chillier than one in a pond, however, we may be less aware of what such warmth reflects and what the ramifications are for pond life. Warmth comes from sunlight, and sunlight is the main source of energy for photosynthetic organisms (and indirectly for the rest of us). It is no coincidence that many ponds turn green with algae during the summer while it is a rare (and usually slow) stream that does so. Of course, following the algae come the algae eaters, so the sunlit warmth of a pond means more life than just more bathers.

Temperature itself affects not only the rate of chemical reactions, but also the oxygen capacity of water. Cold water holds more dissolved oxygen then does warm. Thus, a warm, soupy pond can be low in oxygen not just because more life is breathing oxygen at a faster rate, but also because the water itself is carrying less oxygen. (Green also means more photosynthesis and hence more oxygen production, so the pattern is complex.) Streams tend to have more oxygen not only because they're colder but also because they have the bubbly rapids that, just like an aquarium aerator, inject air into the water. Other researchers have studied the stratification of temperature and oxygen in ponds during different seasons; the consequences for pond life can be dramatic. Our own measurements were too patchy to provide much explicit insight, however they serve to illustrate why the fish, insects, and amphibians of ponds are rarely the same species that one finds in the stream nearby. One does not, for example, usually find Brook Trout in ponds nor Newts in creeks.

<u>Total Dissolved Solids – the Thickness of the Soup:</u> Total dissolved solids (TDS) measures the total amount of materials dissolved in the water; it is a concentration. The rigorous way of measuring this is to evaporate away a known quantity of water and measure the amount of material left behind. This is not convenient outside of the laboratory, and what we measured was actually electric conductivity. Most dissolved materials carry a charge

and so influence the ability of water to conduct electricity. Thus, a measure of a water's conductance can be used to approximate total dissolved solids. Fairly pure water actually can barely conduct electricity (less than 1µS/cm compared to an average of nearly 200 µS/cm in our ponds). To update the wisdom most of us are taught early - it's not actually the water and electricity that is so dangerous, it's the electricity and dissolved salts.

Total dissolved solids cannot be immediately equated with good or bad effects – it depends upon what is in solution. Some ponds may have high TDS because of dissolved road salt; this can threaten pond life. After all, brine has long been used as a preservative because few things can live in it. On the other hand, TDS may also be composed of nutrients. During our work in Venezuela, we studied fish in clear waters draining the ancient Guyanan Shield (conductivity around 8 µS/cm), and compared the fauna to that of muddy waters draining the "recently" raised Andes (dissolved solids more like our ponds). A lot more fish (in terms of weight but not, interestingly, in terms of diversity) were found in the muddy, nutrient-rich waters.[8]

An Aside of Sorts on Multiple Regression—Please Bear with Us

In order to understand a little more about the patterns of TDS in our observations, it's necessary to introduce an analytical technique called multiple linear regression. You may not be all that interested in what's associated with TDS, but we'll use this technique several times during this report, so taking time now to understand it, may help you later. Take a deep breath.

Correlations indicate how two or more variables behave in relation to one another. For example, if one looked at the relationship of goldfish weight to amount of fish food fed per week, one might expect both variables to be positively related, i.e., the more food fed, the heavier the fish. However, you might expect a negative relationship between fish weight and number of fish in the tank (because more fish means less food per fish). Multiple regression is a way of simultaneously looking at the variation caused by several variables, for example, what happens if both amount of food and number of fish vary? It is no secret diviner of relationships, rather the process asks, mathematically, what variable is most strongly related to the given response, counts that in, and then asks which variable is most strongly related with the resulting leftover variation.

There are a variety of caveats, perhaps the most important is that, as we mentioned earlier, correlation does not equal cause and effect. For example, suppose that we found a positive correlation between the weight of goldfish in an office tank and the number of computers in the office. Clearly, we'd be loopy to propose that somehow the computers are nourishing the fish. In reality, more computers may mean more workers and more workers might mean a greater chance that somebody will remember to feed the fish. There are other important assumptions, some of which our data may not meet. For example, you want each data point, or, in our case, each pond to be an independent observation. You would, for example, get a more representative idea of child growth rates if you followed 50 children from 50 different families, rather than 50 children from 10 different families; it is easy to suppose that children from the same family will, because of genetic and upbringing similarities, be more similar to each other than unrelated children. Similarly, some of our ponds were located on the same farm or property rather than being independently scattered across the landscape. There were practical reasons for this, and ponds on the same property were often quite dissimilar. We believe the multiple regression approach is useful for understanding possible patterns in our data. But the results are only suggestions of patterns rather than conclusive proof.

Below is our first example of a multiple regression result, and we'll walk through it in more detail than later analyses. We asked, mathematically, how does TDS relate to a variety of sediment chemicals?

The first step in asking this is to identify the "dependent variable". This means the variable whose behavior we are interested in understanding. It would be goldfish weight in the previous example, and total dissolved solids in our current analysis.

The computer then goes off and runs through the set of variables we provided and comes back with a list of the variables which were most closely correlated with the "dependent variable". These are called the "independent variables" because you are not interested (at least at this stage) in what they are dependent upon. In our case, the computer came back to tell us that sediment calcium, magnesium and potassium were prime correlates of Total Dissolved Solids.

We had all these data from only 70 of our ponds. The "% of Variation Explained" (called R^2 in statistical parlance) is an estimate of how much of the total variation in a sample is explained by the given set of variables.

In our case, the estimate is about 53% of all variation. If this value were 100% then one would be able to pinpoint TDS by knowing the values of just these three variables; such predictability is very rare in nature. We usually start getting excited when % of Variation Explained reaches 15%, but we may just be easily excited.

Dependent Variable: **Total Dissolved Solids**
% of Variation Explained by Model: **53%**
Number of Ponds in Analysis: **70**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Sediment Calcium	**0.650**	**<0.001**
Sediment Magnesium	**0.307**	**0.002**
Sediment Potassium	**-0.369**	**<0.001**

Although you could read just the list of factors and learn something, the analysis provides some additional information. Ultimately, it provides the values needed for predicting the dependent variable from the independent ones. For example, it might tell you that, if you take the number of 5 year-olds in a room and multiply that by 5 and then subtract 2 times the number of mothers you would get sound level in decibels. While such precision can be very useful, we've left that out of the results we'll be presenting. Instead, we've only included the "Standardized Coefficient" and the "Significance of the Effect"; here's what they signify.

Suppose you are interested in knowing how manuring affects tomato production, and you put varying pounds of manure on your garden and count the resulting number of tomatoes. You might find out that you can predict the number of tomatoes produced by a row of tomatoes by multiplying the pounds of manure applied by 10. Tomatoes produced is your independent variable, manure is your dependent variable, and "10" is your coefficient. Now realize that the value of that coefficient depends on what units are used to count tomatoes and weigh manure. If, for example, manure were weighed in ounces, then the coefficient would be 16 times lower; likewise, tallying tomatoes by the bushel rather than by the each would also lower the coefficient. To avoid that problem, we present "standardized coefficients", picture these as unit-free values that you can compare across variables and analyses. They tell you the relative magnitude of each independent variable rather than the exact value: great for comparison, no use for calculating exact predictions. The magnitude of the standard coefficient gives you an idea of how dramatic an effect is; the sign of the coefficient tells you whether the relationship is direct (i.e., positive, e.g., more food means heavier fish) or inverse (i.e., negative, e.g., more fish in tank means lighter fish).

Fig. 17. Tomatoes. You may not need a picture of tomatoes, but this page did need some color.

Finally, the "significance" value (also called the "p-value") is the estimated likelihood that the effect is due to chance alone. These are probabilities. Hence a value of 1 means there is a 100% chance that the observed result is due to chance; a value of .05, means there is only a 5% or 5 in 100 chance that the relationship is due to chance. By convention, values of .05 or less are generally taken to indicate a variable whose relationship to the dependent variable is worth notinge. All the variables in this analysis are highly statistically significant meaning that it's very unlikely we're just looking at a statistical fluke. A significance value of "<0.001" means that the chance of the apparent correlation being simply a random fluke is less than .001 or 1 in 1000. Take these values with a grain of salt and recall that they don't necessarily indicate cause and effect; use them instead to try to gauge the relative importance of the given variables.

Whew! A long, drawn-out explanation about an obscure statistical method for predicting a pond characteristic that you didn't even know you were interested in. Please stick with it. By working through this one example, you'll be much better able to make use of the rest of this report. Here's another set of results to practice on:

Dependent Variable: **Total Dissolved Solids**
% of Variation Explained by Model: **24%**
Number of Ponds in Analyses: **76**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Pond Age (Years)	**-0.165**	**0.119**
% Developed within 400'	**0.294**	**0.005**
Soil Calcareous Class (on 1-3 scale)	**0.348**	**0.001**

But wait! Now, you're telling me that TDS is related to three other variables. Well, it is. Both these relationships can exist in exactly the same way that we could say the sweetness of your tea is directly correlated with the concentration of sugar in your tea water, but is also correlated with the number of spoonfuls of sugar you place in it. In other words, yes, TDS may be chemically determined largely by those three elements we found in the first analysis, however that doesn't tell you anything about where those elements come from and so is, in some ways, trivial. Most of the time, we'll try to skip over the "trivial" cases, but we wanted to think about the different levels of possible cause and effect.

So take a look at these new results. What do they tell you? This set of variables is only half as good at predicting TDS as the first set. However, it's noticeably more interesting because it might give you hints for how to manage ponds so as to influence TDS. Three variables are listed – pond age (it's a pretty weak correlation, notice that the absolute value of the standardized coefficient is the smallest we've seen, and the probability of insignificance is relatively high), % Developed Area, and Soil Calcareous Class (ranked 1-3, from lesser to greater calcareousness). Both the last two correlations seem fairly strong. Finally, notice the sign of the variables. If anything, TDS declines with pond age, that means older ponds tend to have lower TDS. At the same time, the coefficients of the last two variables are positive, that means TDS increases with developed area and soil calcareous class.

Given the above relations between sediment calcium and TDS, and between sediment calcium and soil type, you shouldn't be surprised to find that TDS is also related to soils. The relationship to development is intriguing. Perhaps, it relates to increased erosion, perhaps to water softners, perhaps this is our first statistical fluke… without further study, we don't know, but this relation suggests that, were we particularly interested in TDS, we would want to explore its relationship to development in more detail.

<u>In Sum:</u> From an ecological perspective, these results will only be as interesting as the consequences of pH and TDS for plant and animal life; we'll explore that later on. In relation to our initial aims, we've already shown that aspects of our ponds' environments may stretch beyond their physical bounds in that they are related to the broad geological sweep that produced our soils and perhaps to the land use in the surroundings. It will be interesting to see if we can tie any ecology into this picture.

Our dissection of TDS above, while ushering in unpleasant memories of high school chemistry, is useful for our detective work. In the section that follows, we will explore some of the patterns in sediment chemistry. If we find relationships with land use variables, we'll be able to follow the leads back through the above analyses to factors like pH and TDS. On to pond muck!

In the waters of our ponds, we measured the pH, Total Dissolved Solids (TDS), and Temperature. While such measurements are extremely basic, they began to illustrate relations to the landscape. Specifically, pH and TDS were tied to the presence of calcareous rock, and TDS may also have been linked to the amount of developed land in the surroundings. We present a long, drawn-out description of the pseudo-multiple regression analysis which we used to explore factors related to TDS. We will repeatedly return to this technique in the upcoming pages.

SEDIMENTS

Sediments are not charismatic, but they are important nonetheless. Some are soupy, some are clayey, some are black, some light grey. Some are full of heavy metals, others relatively clean; some are full of nutrients like phosphorus, others are relatively barren. In a very real way, sediments are the groundwork of a pond's ecology. Minerals (and other compounds that we didn't analyze for such as pesticides and complex pollutants) accumulate in a pond's sediments over time. They are brought back into the water by the organisms that mine the muck and by disturbances that carry sediments back into the water. Sediments are reservoirs and historians. They are a great place to continue exploring the bounds, in time and space, of our ponds.

We looked at pond sediments in several different ways: their relative depth, their color, and their chemical composition.

Sediment Depth – A Measure of Time and Erosion: Picture a pond over time. Leaves from the surrounding forest fall in; insects arrive, grow and die; at some point, perhaps fish arrive and live out their lives; algae may turn the water column green before dieing back; and maybe there's a flood and mud-laden waters from a nearby creek wash in. All these materials will, when times are tranquil, sink to the bottom of the pond and accumulate. This scenario hints at four of the factors that probably help determine sediment depth – pond age, pond vitality, the importation of debris from elsewhere, and the amount of water in the pond (to understand this last factor, picture how much sweet glop you'd expect in the bottom of a small tea/coffee/hot chocolate cup vs. a large one). Can we read any of this story in the sediment depth of our ponds?

First a caution – our measure of sediment depth was very rough. We took sediment samples using the same principle we all learn as children: when you stick a straw into your drink and plug the open end with your finger, you can pull out quite a nice sample of your soda. Our "straw" was a metal tube, and, while its "finger end" was not above the water, it had a handy little valve that closed off that end once we had embedded the tip in the mire. We only got as much sediment as our little device captured when it buried itself in the sediments after falling through the water (needless to say, we had it on a string). Because we did not attempt to push our device to the bottom of the sediments and because sediments sometimes leaked out as we pulled our device to the surface (remember dribbling milkshake down your shirt when the straw didn't quite make it to your mouth on time?), our measure of sediment depth is only a minimum. For the sediment analyses we report later, we only used the top 2.5 inches of sediment, both to avoid confusion that might come from including sediments of different depths and because the surface layer is the portion most likely to be relevant to a pond's biota.

The depth of our ponds' sediments was indeed related to pond age (Fig. 18). So think of the years you're plumbing next time you stick your foot deep into pond ooze. The leveling off of apparent sediment depth may be related to the technical issue mentioned above – there was a limit on how deep our device buried itself and on how much sediment we could pull to the surface.

What about the other three factors that we suggested might influence sediment depth, i.e., pond depth, sediment inflow, and pond life? It's time for another multiple regression. Luckily, we had a direct measure of pond depth, however for sediment inflow and pond life, we had to use some possibly suspect substitutes. The closest we came to directly measuring sediment inflow was TDS – after all that is an estimate of total solids in solution which may have some vague relationship with sediment inflow. For an index of in-water life, I used our measure of total algal and plant pigments in solution. Not surprisingly, given that it is probably a very inadequate measure of sediment in-flow, our single measurement of TDS was not statistically related to sediment

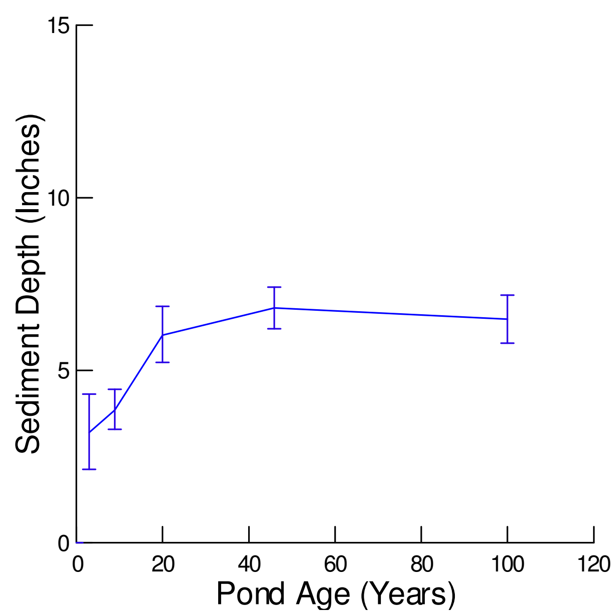

Fig. 18. The depth of pond sediment in relation to pond age; older ponds tended to have deeper sediments.

depth. However, water depth and algal pigments, along with pond age were all relevant (don't worry that pond age entered twice, you know the pattern from the above graphic; these permutations are, again, necessary for statistical purposes). All's well, right? Wrong. Look more carefully at the model details below, what result does not agree with our evidently simplistic attempt to explain pond sediment dynamics?

Dependent Variable: **Sediment Depth**

% of Variation Explained by Model: **26%**

Number of Ponds in Analyses: **70**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Pond Age	**-0.287**	**0.155**
Pond Age (Square Root)	**0.431**	**0.035**
Water Depth	**-0.346**	**0.003**
Total Dissolved Pigments	**0.222**	**0.044**

Perhaps Fig. 19 will help.

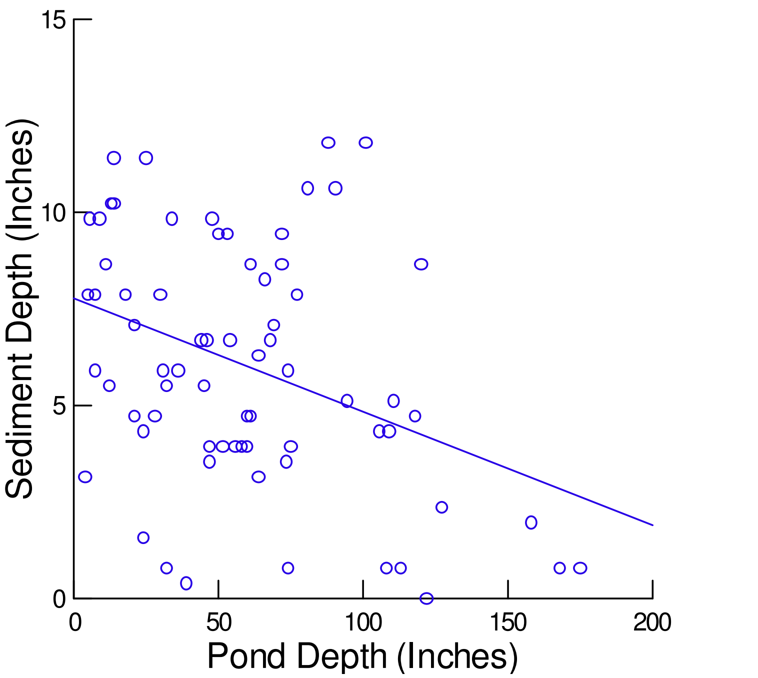

Fig. 19. The relation between pond depth and sediment depth—deeper ponds had shallower sediments!

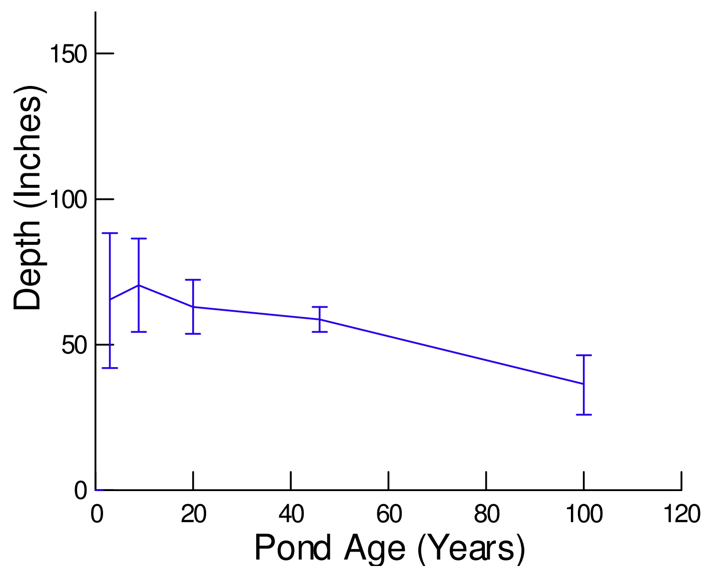

Fig.20.Water depth versus pond age. Ponds tend to fill in as the age and older ponds may not have been dug as deep as modern ponds.

Look again at the sign of the coefficient associated with Water Depth; it's negative. As that sign and the above graph suggest, sediment depth *decreases* as water depth *increases*. That's not the relationship we'd predict if sediment depth were being determined in part by material growing in and then filtering down out of the water column above. Figure 20 might help explain this paradox.

In words, older ponds tend to be shallower than younger ponds. There may be several reasons for this, including distinct, historical differences in the motivations of pond digging (e.g., currently dug in part as deep swimming ponds, previously intended in part as shallow cattle watering holes). Another contributing factor may be the apparent life cycle of ponds – almost all ponds gradually fill up with sediments over time. Although pond age was already in our model, apparently water depth added some additional detail to our predictions of sediment depth, perhaps because we had not fully accounted for aspects of pond aging.

If you carry something away from this short foray into pond sediment dynamics, it should be the mutability of ponds over time. The relationship that we have already documented between pond age and sediment depth, if extended over centuries, has the logical conclusion of a shallow, sediment-filled pond that eventually even reverts to dry land. Some have even proposed that the valley bottoms where much of our agriculture occurs are the ancient remnants of beaver ponds. While that might be an exaggeration, there is no doubt that ponds have a life in time. Not only do their lives reach beyond their shores they reach backwards and forwards to changes over time.

Sediment Color – A Slow, Wet Fire: Ok, so how many of you, having stepped into that pond ooze, quickly retreat to shore to examine the color of the few globs still stuck between your toes? Studying sediment color sounds esoteric, but it can actually help us learn more about our ponds. The main reason that it is revealing is that one can make useful generalizations from pond color. All else being equal, pond bottoms around here often start out the grayish color of clay. Over time, mud and organic material accumulates and darkens the sediments. Very black sediment indicates the presence of "organic matter" (a scientists way of saying dead things); basically, the blackness is charcoal, albeit the charcoal produced by the slow flame of biological decomposition. Given this interpretation of sediment coloration, we may be able to learn something about the life of our ponds.

We measured color categorically as light, medium, and dark (Fig. 21). No doubt there are gradients but the end points (grey and black) were clear enough, and anything that didn't qualify for those categories was called "medium". We'll explore two ramifications of our above proposal – young ponds should have lighter sediments, and ponds in landscapes producing lots of organic matter run off should have the blackest sediments. Figures 22 and 23 appear to support both of these conjectures.

Fig. 21. Sediment color from our ponds. The black streaks at left are traces of organic matter that have accumulated in the upper portion of the sediment. The middle picture shows a more common sediment color—traces of organic matter darkening mixed with a more mineral grey (as is also apparent in the lower portion of the sediment at left). On the right, the tip of a core into a largely mineral sediment with patches of clay-like grey. These sediments would have been ranked as dark, medium and light respectively.

That the mineral sediments of new ponds might be greyer (the pattern is not quite statistically significant) should not come as a surprise. The strong (and statistically significant) relationship with plowed land might be more surprising. These data might suggest that plowing land increases the loss of its organic matter. This would assume that most of the organic matter comes in as erosion, rather than through the accumulation of in-pond biological production. In fact, the loss of organic matter from plowed fields is a well-recognized issue in agricultural sciences. Does this increased organic matter affect the organisms that live in our pond? Are we beginning to forge more links between pond and surroundings? We shall see.

This is a good spot for another caveat. The statistics which we present are selective. I did not show you, for example, the rather dull plots of soil color vs. land in lawn or development or pasture. Indeed, we looked at these to make sure that the pattern with plowed land was, in fact, something distinct. Likewise, in our earlier multiple regressions, we did not tell you which factors entered into our tests, but did not turn out to be

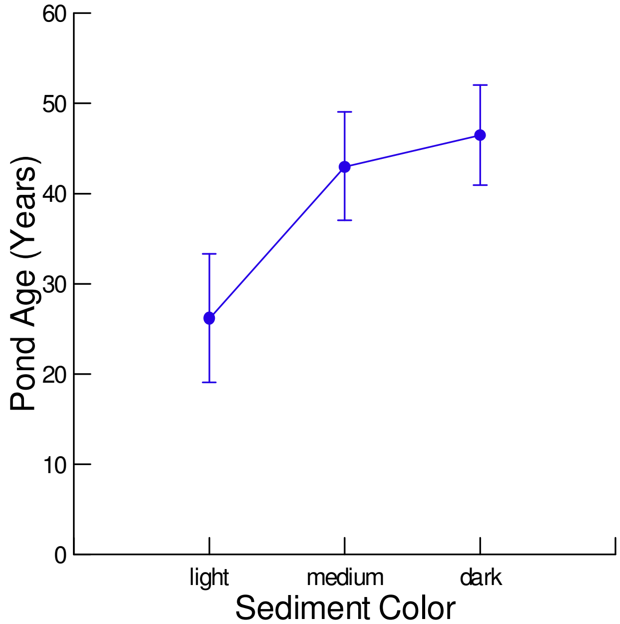

Fig. 22. Sediment color in comparison with pond age. Older ponds had darker sediments, probably because of the accumulation of organic matter (i.e., dead stuff).

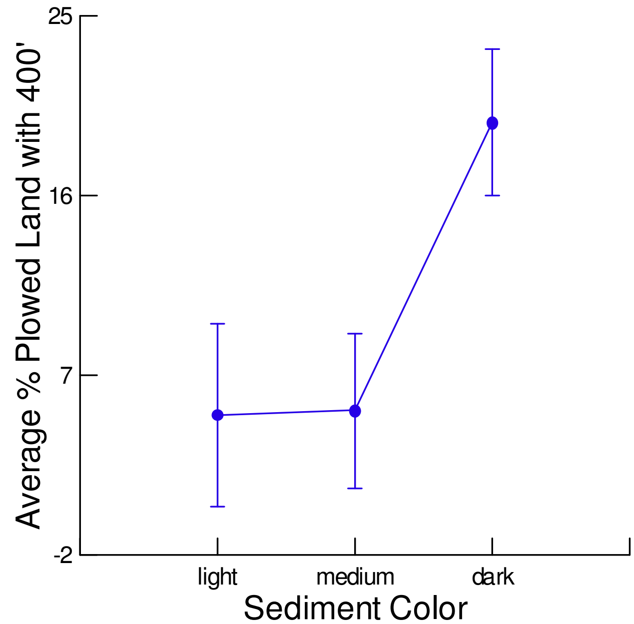

Fig. 23. Sediment color in relation to amount of plowed land in a pond's surroundings. Plowing in adjacent land may increase organic matter run-off into ponds.

significant. We'll plead conciseness –this text would become even duller and denser were it to include a listing of all dead ends. However, you could also accuse us of stacking the deck, only presenting those results that fit our case. The appendix contains the full statistical details of the different analyses that are summarized in the text. Please do look at it if you want to getter a better idea of how this paper was constructed. Otherwise, we will only say that yes, we did do a fair bit of fishing for patterns, but we have tried to be honest and include all those relationships which appeared strong, whether or not we could explain them.

Sediment Content – Distilling our Wastes: Imagine that you want to understand something about the lives of people that live in a single faraway city by following their diets. You interview many people and get a long list of all the foods eaten. You describe each person based upon the foods they eat, how many pounds of mangos, marshmallows and what have you. You end up with a huge data set and then what? One approach is to try to categorize the data based upon diets, i.e., upon clusters of foods that tend to appear together. For example, one might find that there is a group of people who tend to consume both rice and beans. Proceeding in this way, you might come up with distinct food clusters that will help you identify patterns that subsequent analysis including, for example, ethnicity, might elucidate. This scenario illustrates the motivation for a technique, called principal component analyses, that we will shortly apply to our sediment data, but first, to quote Kai Ryssdall, "let's do the numbers". They are not terribly happy ones.

As settling ponds for what rains down upon them and runs off of the surrounding lands into them, ponds accumulate the dirt that falls from the sky or washes from our activities. Much of this dirt ends up in a pond's sediments. A certain amount of such accumulation is natural and so, as we look at the concentrations of various heavy metals and other elements in pond sediments, we need a reference point. What concentrations are natural, which unnatural, which might cause biological problems?

Little work has been done on ponds, so we must turn to lake sediments. Table 1 is a summary assembled by the state of Wisconsin using information from a variety of sources. It shows the biologically-relevant concentrations for a limited set of elements. We used these data to evaluate the potential ecological importance of the concentrations we observed in our pond sediments.[9]

Table 1 can be used to classify the concentrations of any of the listed elements into four classes: values unlikely to cause environmental effects, values where an effect might first occur, values where such an effect has medium likelihood, and values where an effect is probable. Figure 24 indicates that for some of the elements, (e.g., iron, lead and manganese) concentrations in many ponds may have been high enough to have environmental effects, while other elements rarely showed high concentrations. With antimony, for example, all 86 ponds showed minimal signs of contamination, while, for lead, 71 ponds showed medium or high levels of contamination. Although not shown in Table 1 or Figure 24, sediment phosphorus exceeded presumed background levels in 95% of the ponds.

If green indicates "comfortable" background levels, then multi-colored Figure 24 is cause for

Metal	mg/kg dry wt.**						
	Level 1 Concern ≤ TEC	TEC	Level 2 Concern > TEC ≤ MEC	MEC	Level 3 Concern > MEC ≤ PEC	PEC	Level 4 Concern > PEC
Antimony	⬅	2	⬌	13.5	⬌	25	➡
Arsenic	⇦	9.8	⬄	21.4	⬄	33	⇨
Cadmium	⇦	0.99	⬄	3.0	⬄	5.0	⇨
Chromium	⬅	43	⬌	76.5	⬌	110	➡
Copper	⇦	32	⬄	91	⬄	150	⇨
Iron	⇦	20,000	⬄	30,000	⬄	40,000	⇨
Lead	⇦	36	⬄	83	⬄	130	⇨
Manganese	⇦	460	⬄	780	⬄	1,100	⇨
Mercury	⬅	0.18	⬌	0.64	⬌	1.1	➡
Nickel	⇦	23	⬄	36	⬄	49	⇨
Silver	⇦	1.6	⬄	1.9	⬄	2.2	⇨
Zinc	⇦	120	⬄	290	⬄	460	⇨

Table 1. A table showing the concentrations in lake sediments at which various elements become of environmental concern. TEC = Threshold Effect Concentration; MEC = Midpoint Effect Concentration; PEC = Probable Effect Concentration. Taken directly from a Wisconsin DNR 2003 publication. [9]

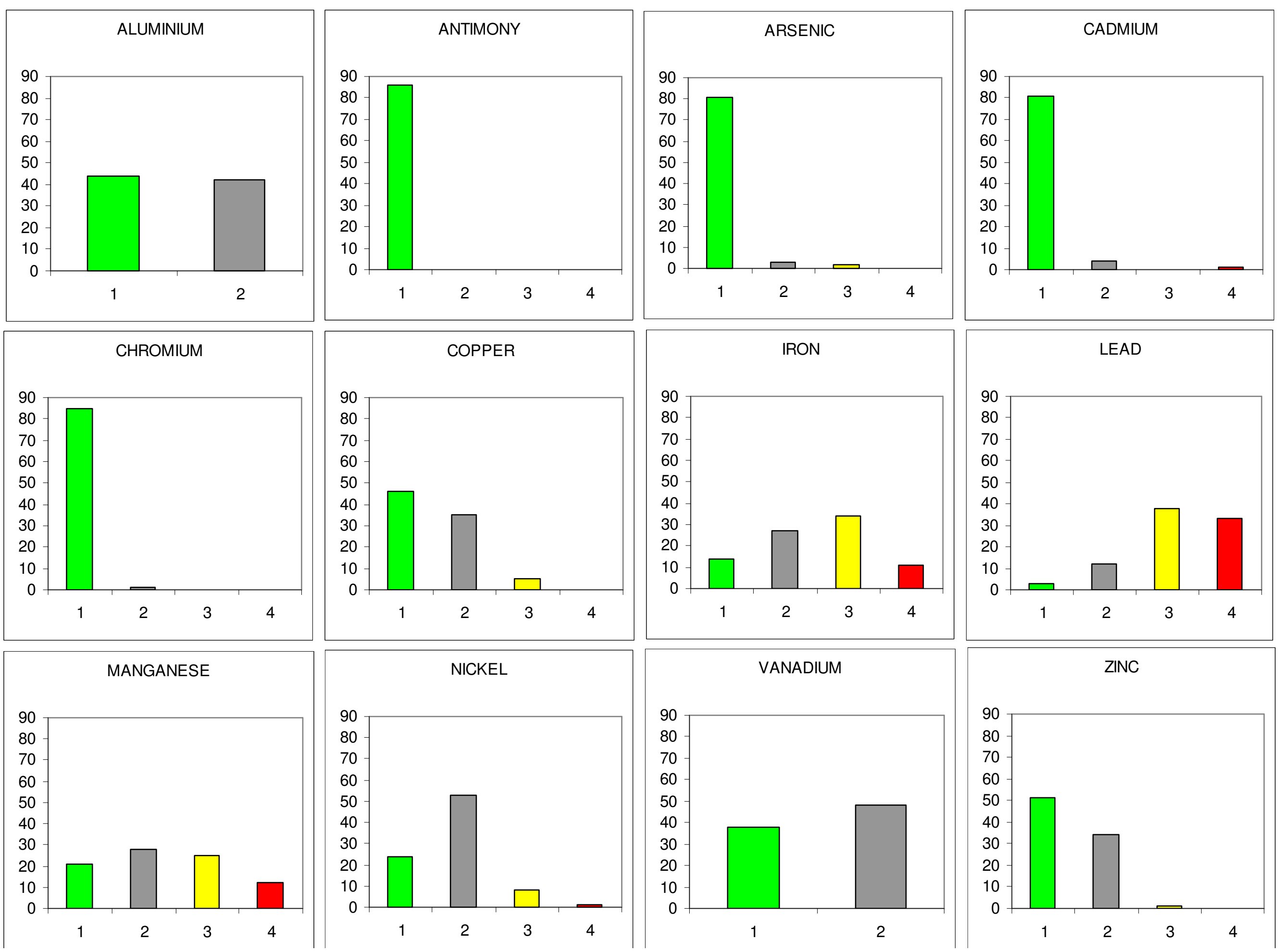

Fig. 24. A set of histograms indicating the number of ponds (86 total) in each Sediment Contamination Class for several elements of environmental relevance. Most classifications are based upon the data in table 2; additional published information estimating background levels was used to calculate a below/above categorization level for several additional elements (those with only two categories in their histograms). Contamination level increases from 1-4 (green –red); class 1 (green) is considered non-contaminated.

concern. Most of the elements listed showed evidence of unnatural enrichment. In some cases, that enrichment reached levels believed likely to threaten biological health. Later we'll see if there actually is any evidence in our data for such effects. However, before doing that lets apply our principal component analysis to these data in an effort to look for patterns in the numbers. If, as we have suggested, the chemistry of pond sediments reflects input from outside, then there should be some evidence of such patterns in our data.

A principal component is, essentially, a set of variables that co-vary. Each component is thought to identify one pattern of covariation in the data (i.e., one diet, to continue our gastronomic example). A principal component is expressed as a series of coefficients indicating the contribution of each individual factor to the given component (or each food to the diet). As such, the general "nature" of each component can usually be identified by looking at the factors most heavily influencing it. While the mathematics is somewhat complex, inspecting Table 2 may give you a 'feel' for what such components represent. We will use these components in some of our subsequent analyses exploring the relations of biological variables to landscape and sediments. Therefore understanding what they represent will help you understand some of what comes later.

Our principal component analysis identified 7 clusters of like-behaving "components". To return to our initial dietary example, the elements would be represented by the different foods, while the components would

Sediment Components

	1	2	3	4	5	6	7
Aluminium	0.925	0.104	0.094	-0.066	-0.261	-0.020	-0.001
Antimony	0.882	-0.318	-0.110	0.082	0.206	-0.093	-0.032
Arsenic	0.087	0.318	0.296	-0.115	0.646	-0.099	0.142
Barium	0.442	0.509	0.377	0.214	0.042	-0.228	0.312
Beryllium	0.800	0.154	0.293	0.019	-0.200	-0.234	0.087
Boron	0.746	0.025	0.172	0.118	0.121	0.367	-0.163
Cadmium	0.071	-0.026	-0.342	0.323	0.027	0.259	-0.297
Calcium	-0.162	0.571	-0.611	0.261	0.181	0.058	0.185
Chromium	0.933	0.111	0.049	-0.130	-0.195	0.005	0.031
Cobalt	0.797	-0.393	-0.097	-0.078	0.254	0.023	0.048
Copper	0.247	0.383	0.077	-0.322	0.279	0.292	0.260
Iron	0.855	-0.349	-0.119	0.095	0.234	-0.102	-0.028
Lead	0.956	-0.002	0.054	-0.019	-0.062	0.037	-0.118
Lithium	0.870	-0.025	-0.151	0.086	-0.137	-0.179	0.005
Magnesium	0.562	-0.179	-0.509	-0.153	0.141	0.081	0.158
Manganese	0.394	-0.268	0.268	0.523	0.334	0.053	0.147
Molybdenum	-0.126	0.338	0.156	-0.374	0.459	-0.141	-0.431
Nickel	0.763	-0.274	-0.188	-0.313	0.115	0.033	0.096
Phosphorus	0.804	-0.285	-0.170	0.125	0.238	-0.191	-0.018
Potassium	0.730	0.517	0.139	0.071	-0.204	-0.013	0.034
Selenium	-0.190	-0.164	0.540	0.461	0.092	0.446	0.143
Sodium	0.610	0.223	-0.161	0.266	-0.255	0.084	-0.205
Strontium	0.066	0.619	-0.523	0.348	0.081	-0.049	0.147
Sulfur	-0.024	0.610	0.009	0.155	0.242	-0.113	-0.467
Titanium	0.297	0.329	-0.159	-0.382	-0.039	0.521	0.179
Vanadium	0.763	0.415	0.212	-0.141	-0.155	-0.034	0.012
Zinc	0.603	0.038	0.121	-0.013	-0.015	0.309	-0.386

1 = Broad enrichment
2 = Ample Barium, Strontium, Calcium, Potassium & Sulfur
3 = Lack of Calcium, Magnesium & Strontium
4 = Elevated Manganese?
5 = Elevated Arsenic
6 = Elevated Selenium, Titanium
7 = Lack of Sulfur, Molybdenum, Cadmium, and Zinc

%variability accounted for	39.7	11.2	7.5	5.7	5.5	4.1	4.0

Table 2. A summary of the principal components identified in our sediment elemental data. Seven components were identified. The green tints indicate medium (light green) and strong (dark green) positive contributions to each component; reddish tints indicate medium (pink) and strong (dark red) negative contributions. Below the list of elements, is our summary of the components. Along with the amount of total variability accounted for by each component.

represent the seven different diets that we might try to associate with ethnicity. The values below each component and across from each element (for example, the .925 that is to the right of aluminium and below component number 1) are the component loadings. You can think of these as the weights of foods that went into each diet. These values vary from –1 to +1 with negative numbers denoting a relative absence of a given component (e.g., pork's absence from the Kosher diet).

In Table 2, we have tried to summarize some of the key characteristics of each component. "% variability accounted for" shows how much of total variation was accounted for by the given component. Imagine, for example, the power that identifying vegetarians vs. non-vegetarians would have in explaining our regional diets; in contrast, realizing that some people have vinegar on their spinach would be substantially less powerful and would account for less of the total variation.

In the same way that we explored the correlates with Total Dissolved Solids, we explored the relation of each sediment component to various habitat and pond characteristics, and we summarize those results below.

Sediment Component 1– By Land & Air?: The first component was powerful – it was associated with elevated levels of a broad range of elements, including most heavy metals. Yet, our correlates while statistically significant, explained less that a quarter of the variation. Here's the multiple regression report:

Dependent Variable: **First Sediment Componen**

% of Variation Explained by Model: **21%**

Number of Ponds in Analyses: **66**

Significant Variable	Standardized Coefficient	"Significance" of Effect
No. of Nearby Houses	**0.260**	**0.027**
pH	**-0.294**	**0.012**
Sediment Depth	**-0.341**	**0.004**

Not surprisingly, perhaps, the number of buildings (houses, barns, workshops, offices, etc.) within 400' of the ponds was positively correlated with this component (Fig. 25). If this component does represent the general effluent of society and if the number of buildings indexes the intensity of human use, then the correlation seems reasonable. While the relationship between this sediment component and buildings seems apparent in the graph and seems interpretable, we should caution that aside from the previously-mentioned lack of independence in our data, relationships in which the values of at least one variable are clustered to one side (i.e., the predominance of ponds without surrounding structures in Fig. 25) run the risk of being misinterpreted. Notice how much power the relatively few ponds surrounded by four or more houses have in leading the eye (and the statistics) to assume a certain relationship. Such correlations are thought provoking and worth mentioning, they are not however conclusive.

The negative relationship with pH (fig. 26) may relate to the tendency, mentioned earlier in relation to plant nutrients, for elements to be more closely bound to the sediments at acidic pH's. This could result in lower leaching or dissolution of sediment elements and hence higher sediment elemental values at lower pH's. We can't immediately explain the relationship to sediment depth (Fig. 27). As we mentioned earlier, sediment depth was linked to a variety of other factors including pond age and water depth.

Part of the unexplained variation in this component, may relate to the fact that not all (or even, perhaps, most) of these elements originate from neighboring ground sources. The elements that contribute strongly to this component are at least partially supplied through air-borne particles. To a large degree, they are impurities present in fossil fuels. They are liberated upon burning and spread through the air in smoke. We are downwind from much of the country's industrial production, and it shouldn't be surprising that this is evidenced at the bottoms of our "collecting basins". What determines the collecting propensity of a pond probably has to do with location relative to weather systems and nature of each pond's watershed, factors beyond our ken.[10]

Sediment Component 2– The basics: This component seemed to follow pond alkalinity. It was highest in

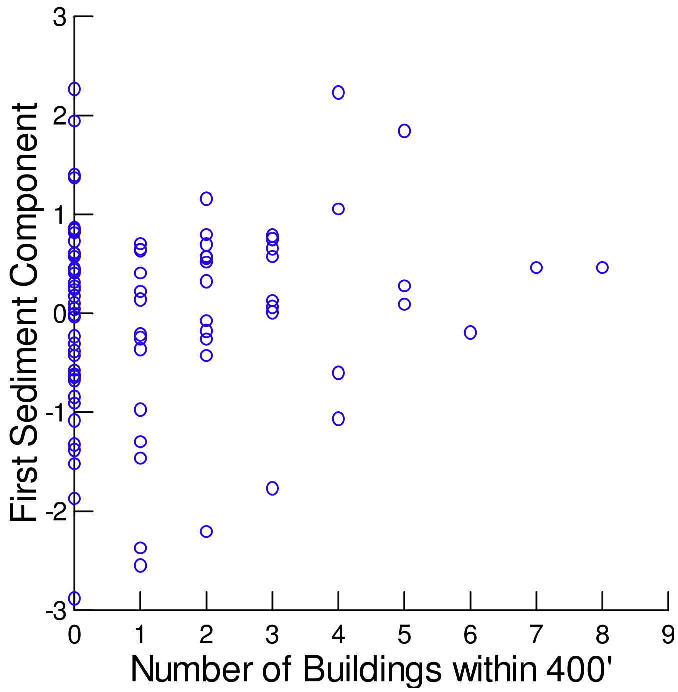

Fig. 25. The relationship between the number of buildings within 400' of a given pond and that pond's value on the first sediment component. This components tends to increase with increasing number of nearby buildings, however notice how many samples are clustered along the left of the graph, allowing relatively few ponds to determine the apparent pattern. We have left the linear fit out of this diagram, so that you can better appreciate the effect of the extreme points.

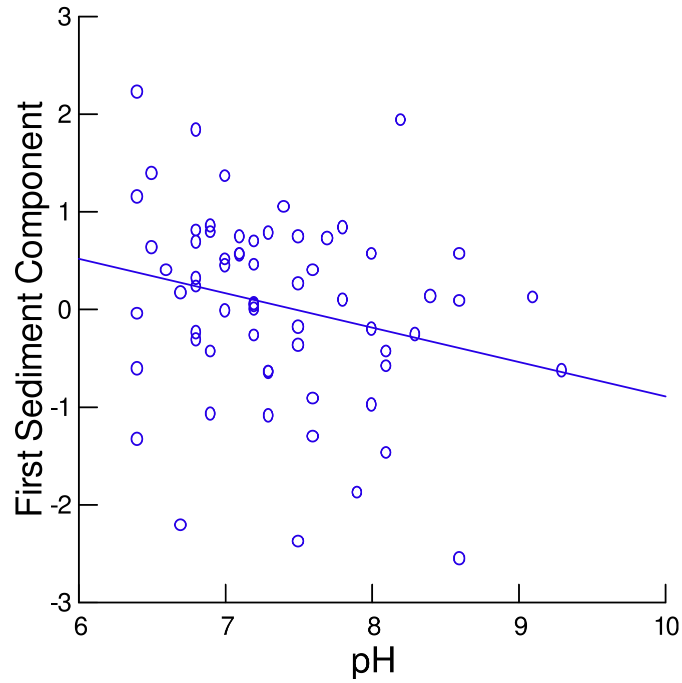

Fig. 26. The relation between water pH and our first sediment component. This component tended to decrease with increasing pH.

sediments with relatively high calcium and magnesium, and its value rose with pH.

Multiple regression indicated that as pH increased (became less acidic), the second sediment component increased (Fig. 28); it also increased as distance to nearest forest decreased. The first observation is not difficult to understand – this second component represents some of the elements typical of sediments (and soils) that are non-acidic; the relationship to forests may have to do with the elements introduced by leaf fall (Fig. 29) . The leaves of some trees, such as basswood, are rich in calcium and potassium, and so nearby forests might help boost the concentrations of these elements in a pond. However, we would need to look at leaf fall and leaf chemistry, if we wanted to explore that relationship further.

<u>Sediment Components 3 through 7–The Fringe Elements</u> The remaining sediment components have less predictive value and, aside from component 5 which appeared to be associated with elevated arsenic, may be more difficult to summarize. Components 5 and 7 both increased as house proximity increased, and component 6 increases with amount of developed area nearby. It would be interesting to compare arsenic levels with proximity to former orchards given the historical use of arsenic as an apple fungicide, but we haven't yet collected those data. All seven sediment components showed higher levels in residential than agricultural ponds, but the pattern had only marginal statistical significance.

<u>Phosphorus–How Green is my Pond</u> Before finishing our consideration of pond sediments, there is one element that we wish to consider individually because of its potential ecological importance – phosphorus. Phosphorus, at least at the levels that we encountered, is not a direct toxin. Rather, it is a fertilizer. We say not a "direct toxin" because, while it may not poison organisms directly, some organisms are adapted to living in low nutrient conditions, and soon disappear when increased nutrients boost their competition.

Baron Justus von Liebig is a worthwhile character to introduce into our narrative at this point. A German paint-mixer's son born in1803, his career typifies science's mixed blessings. Liebig's Law, like all "laws" in ecology, is a useful generalization rather than a law. It stated that the growth of plants was limited by the

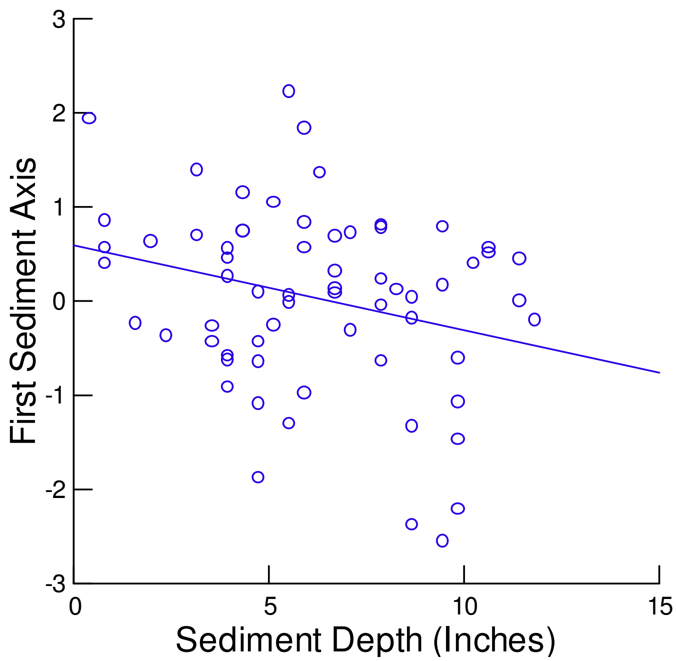

Fig. 27. The first sediment component compared with sediment depth. Deeper sediments were associated with lower levels of this component

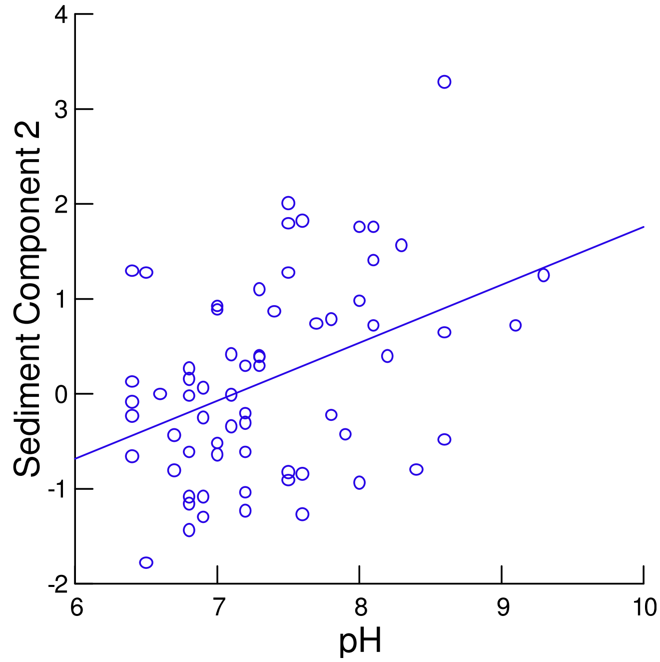

Fig. 28. The second sediment component increased in value with increasing pH. It seemed to largely reflect the pH gradient of our ponds.

nutrient that was in shortest supply. Although this statement is somewhat circular (because "shortest supply" must be calculated in a way relevant to the plant, this law almost translates into "plant growth is limited by that nutrient which limits the growth of plants"), it is a useful thinking aid. It focuses attention on the idea that a particular nutrient might limit growth, and that, once that nutrient is satisfied, another might become the limiting factor. Liebig was one of biochemistry's founders, and he applied much of what he learned to agriculture. He pioneered the idea that nitrogen fertilizer could boost plant growth and promulgated the concept that synthetic fertilizers might work just as well as natural ones.

Liebig deserves a cameo because his "law" and the industrialization of fertilizer both play a part in understanding pond ecology. Observers studying the nutrition of pond plants have found that phosphorus is often a limiting nutrient in the sense of Liebig's Law. The addition of phosphorus to a pond often results in a bloom of growth. That addition can come through Liebig's legacy, i.e., synthetic fertilizer applied to neighboring land (the "P" of NPK fertilizer is phosphorus); but it frequently comes from less conscious additions such as contamination by sewage or phosphorus-containing soaps. In any case, phosphorus addition to waterways is now recognized as one of the main causes of *eutrophication*.

Fig. 29. A Columbia County woodland pool (not one included in this study) collects autumn leaf fall from the nearby forest.

Eutrophication refers to the process where by a pond becomes increasingly enriched in nutrients and, as a result, the community structure of pond life is altered. A pond clogged with green algae due to phosphorus run -off is one example. Eutrophication may happen very slowly due to natural processes associated with pond aging, but the rapid eutrophication of ponds and other waterbodies due to human activity is thought to be one of our major impacts on aquatic ecosystems.[11]

There are various ways of measuring degree of eutrophication. Some are based on trying to index the flush of life that is caused by enhanced fertilization; others try to measure the chemistry of fertilization directly. At this point in our story, we will look at sediment phosphorus. Although the phosphorus *in the water* may have a more direct impact on pond life, phosphorus *in the sediment* may be the sleeping giant – the phosphorus present in the top layers of sediment is usually much higher than what is in the water and it can be returned to the water by diffusion, nutrient mining by organisms, and sediment disturbance. Phosphorus in-flow could be removed from a pond, and eutrophication might continue to occur because of the buried phosphorus stores. The phosphorus in more than 95% of our ponds appeared to be above background levels and so might be causing some ecological effects. Is there any evidence of this scenario in our data? Here's another regression analysis:

Dependent Variable: **Sediment Phosphorus**
% of Variation Explained by Model: **18%**
Number of Ponds in Analyses: **66**

Significant Variable	Standardized Coefficient	"Significance" of Effect
pH	**-0.274**	**0.020**
% Developed within 100'	**0.233**	**0.047**
Sediment Depth	**-0.270**	**0.023**

We've included pH and sediment depth in the analysis not because we understand why these patterns occur or particularly want to discuss them. Rather, before we look for a relationship with land use, it's useful to get rid of as much "extraneous noise" as possible, although there's always the risk of throwing the baby out with the bath water (e.g., what if some byproduct of development affected pond phosphorus by altering pond pH?). Inspect the results above – the only land use variable that significantly predicted pond sediment phosphorus was % developed area within 100' of the pond edge (fig. 30). This fits with the patterns of contamination recognized by others. Interestingly, adjacent agricultural habitats appeared to have no such effect.

The correlation with development was not particularly strong. For example, there were many ponds that had no development within 100' but which nonetheless showed relatively high levels of phosphorus. However, high development was associated with higher than average phosphorus levels. The same caution that we mentioned in relation to house number and our first sediment component again applies here because relatively few ponds were surrounded by 20% or more developed land.

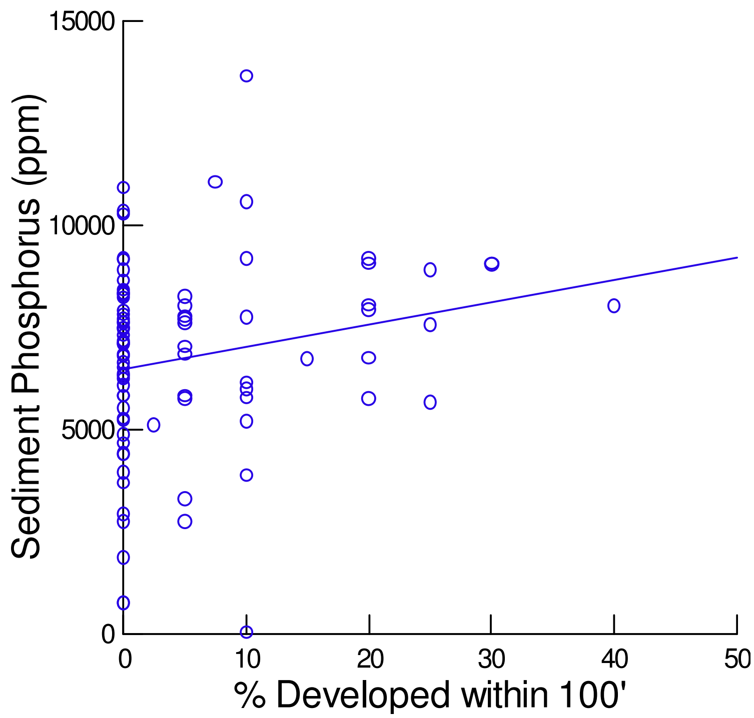

Fig. 30. Amount of sediment phosphorus and % of developed land within 100' of a given pond. There was a tendency for phosphorus concentration to increase with developed land although note the wide range of phosphorus values associated with 0% developed.

In sum, we have looked at the physical and chemical aspects of our ponds, and highlighted some apparent connections to the surrounding landscape. Ponds are not indoor swimming pools isolated from their surroundings, but rather aquatic patches of landscape that extend out in many directions. In the sections that follow, we finally move on to pond life – how do the plants and beasts we find in our ponds reflect this linkage to the greater environment? Are they too strings that connect sky and earth, water and dry land?

Pond sediments accumulate the various materials that enter them as direct deposition in rain or dust, and as run-off from the surrounding land. Sediment depth reflects pond age, while sediment color appears related to the surrounding land use. The sediments of our ponds were high in some heavy metals. This contamination was partially correlated with surrounding land use and may also have derived from aerial deposition.

Part II: Pond Life

Pond life illustrates a pond's connection to its surroundings in two ways: first, as we have mentioned, because what happens around a pond can trickle into a pond and affect the organisms living in it; and, second, because during different stages of their lives, some pond organisms move to and from ponds, and so their survival requires good upland, as well as lowland, habitats. As examples of the latter, some frogs and salamanders only come to ponds for one brief, seasonal orgy, before returning to surrounding land; dragonflies stalk mosquitos and blackflies far and wide before returning to their in-pond nurseries; and the caterpillars of some wetland butterflies may require sedges, but the adults can benefit from the nectar of upland flowers. Because of these forays, what's happening on the surrounding land can directly determine the health of these organisms.[12]

Our section on pond life will introduce you to some of the creatures that live in our ponds. Ponds are fascinating zoological and botanical 'gardens'. We will touch upon some of the concepts that we have already introduced. We'll meet eutrophication again. This time, instead of looking for possible contributing factors to pond greening, we'll try to index the greening itself. In considering the abundance and diversity of plants, we'll visit Baron von Liebig again and ask what nutrients might be affecting their communities. And, in considering the role of landscape in determining the abundance of different animals, you'll get a chance to see even more of those little mathematical equations that are no more than very rough sketches of the patterns that may exist in the underlying tapestry of nature.

A Methodological Aside

Conventional scientific papers put all of their methods at the beginning. That makes it easy to refer to them when necessary and easy to skip when not. We've put our methodological details in the appendix, but there are certain methods that we really think you should know about because they are central to much of the work presented here and because they help you begin to see the ponds in the same way we do. One of those methods is habitat analysis using "remote sensing". "Remote sensing" does not mean E.S.P., instead it refers to the use of satellite and aerial photographs to describe characteristics of the landscape. As anybody who has flown knows, seeing the land from above brings whole new insights into what's happening on the ground. As anybody that has flown also knows, there often comes a point at which a visit back to ground level is key to understanding mysterious patterns. Good remote sensing work uses both the remote image and what is called "ground-truthing", i.e., visits to those places that you've described from the photographs in order to insure that, for example, the dark swaths that one has been calling evergreen forest from the air are not really broccoli patches. In order to better understand

Land Use Descriptors Derived from Aerial Photographs

- *Number of Buildings within 400'*
- *Distance to Nearest Building*
- *Distance to Nearest Forest*
- *Distance to Nearest Road*
- *Total Length of Roadway within 400'*

Coverage Estimates (Measured Twice - within 100' and within 400' of the pond):

- *Percent Wooded*
- *Percent Lawn*
- *Percent Plowed*
- *Percent Hay Field*
- *Percent Pasture*
- *Percent Water*
- *Percent Developed*

Table 3. A list of the landscape characteristics that we measured using aerial photography and ground-truthing. The 100' and 400' rings were chosen based upon published data looking at the interaction of amphibians and land use; the 100' ring indicates immediate surrounding conditions, while the 400' ring gives a broader view of general context. These two measurements are often closely correlated for a given characteristic.

what was happening in our ponds, we did the same thing: we combined inspection of aerial photographs with on -the-ground visits to insure we were interpreting things correctly.

Table 3 shows the landscape variables we calculated and the figures that follow show a couple of examples so that you can get a feel for what these variables really meant. Don't get hooked, there's something powerfully omniscient about these aerial views!

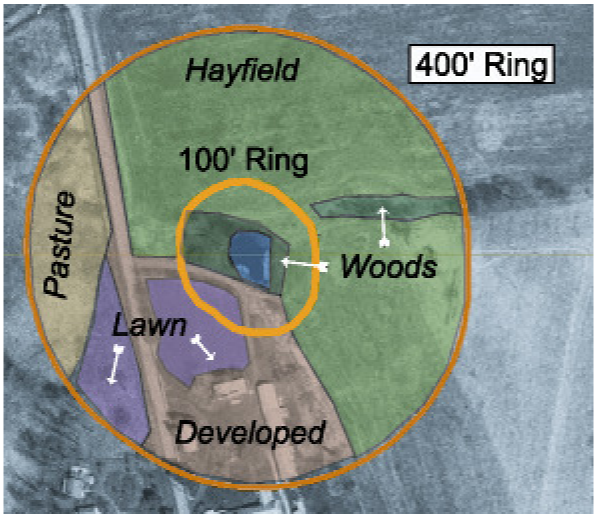

Fig. 31. An illustration of the land use quantification done around each pond at a distance of 100' and 400'. The categories used were lawn, developed, woods, pasture, hayfield, plowed cropland, and water. Percentages occupied by each land use were estimated in donuts extending 100' and 400' from the pond.

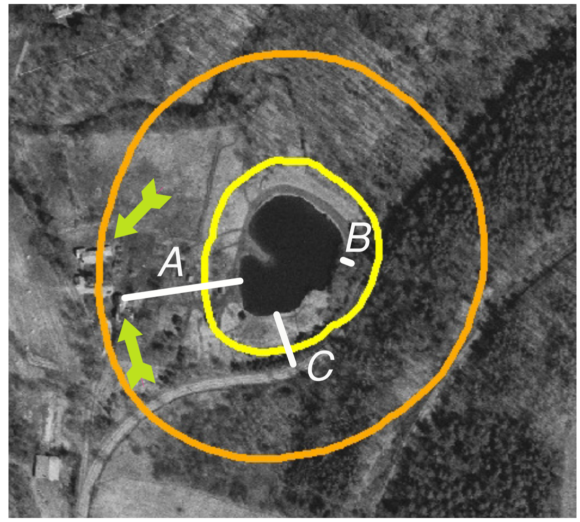

Fig. 32. An illustration of some of the landscape measurements we took using aerial photographs. Buffer rings are at 100' and 400' from the pond. Green arrows indicate larger buildings falling within 400' of the pond. **A** *= distance to nearest house,* **B** *= distance to nearest forest, and* **C** *= distance to nearest road.*

Basically, for each cover type, we calculated, by eye, the proportion of a 100' and 400' fringe around each pond that was occupied by the given cover. For example, in Fig. 31, we would have said that within 100' there was about 30% Woods, 35% Hayfield, 20% Developed and 15% Lawn, while within 400' there was something like 50% Woods, 10% Pasture, 10% Woods, 15% Lawn and 15% Developed. We did several line measurements on the aerial photos – distance to nearest road, forest and house, plus total length of roadway within 400' (Fig. 32). Bank characteristics and approximate amount of wetland in the surroundings of each pond were done based on experience during our visits to each pond. These are all rough measures, but done across 90 ponds and with an individual knowledge of each pond, we think they provide a useful summary of general pond context—.

ALGAE

Chlorophyll—The Very Nature of Green: People don't like green ponds. We are accustomed to bathing in clear water, not pea soup. Much of this is aesthetic, although a few types of algal blooms can be toxic. That said, some greening is probably as natural as growing old. Our life-spans are very short relative to the timing of some ecological processes. One of these processes is the life of a pond. Ponds are rarely stable in time. They are "born", grow old, and "die". "Birth" may occur for natural reasons (e.g., puddling in rocky basins, empoundment by beaver or other natural happenings) or because humans build them. In either case, they grow old. The aging of a pond involves its being in-filled and fertilized by the accumulation of debris and nutrients. Again, this may be a natural process during which actions such as leaf-fall, aquatic plant growth, and the arrival of natural creek-born sediments slowly fill the pond in, or it may be the relatively rapid result of human action which accelerates sedimentation and fertilization (here and below, "fertilization" refers to increasing available nutrients; it may or may not be associated with intentional fertilization of lawns, crops, or ponds). The arrival of nutrients from outside of a pond will affect plant growth within the pond, and the more plant growth within the pond, the more nutrients are captured and deposited by plant life, further speeding up the aging process. Figs. 33

-41 show ponds of varying shades of green because of different types of algal and plant growth.[13]

The aging process can be dramatically accelerated by human action. For those who might say, 'ah, but you just said it's a natural process, so what's the fuss?', picture what would happen if some newly released chemical suddenly caused humans to age 100 times faster than normal – we would soon have a very decrepit and non-functional adult population in many places. While ponds obviously don't breed and so we can't push this analogy too far, they do harbour different life forms during different stages of their existence. Some organisms do just fine in eutrophied ponds, but many are adapted to the earlier stages of a pond's existence. Rid the landscape of a proportion of relatively clean, middle-aged ponds, bordered by a wide strip of wet meadow, and you rid the landscape of all the organisms who became adapted to live in such areas. For example, a little noticed consequence of our re-formation of ponds has been the decline of the muskrat. Just its name implies it's as common as the fleas on a dog's back. However, this rodent, somewhat smaller than a groundhog and, taxonomically speaking, a giant vole, has been steadily disappearing from our countryside. One possible cause for the decline is that the marshes it favors are not favored by humans who prefer dryland or distinct ponds.

If we go grey with age, ponds go green (at least in many places and within limits; natural aging will rarely lead to the dramatic overfertilization typical of some human effects). Why green? What turns your pond green is often algae. "Algae" is a grab-bag term for an array of plant-like organisms that do not quite have the structural complexity of true plants, even though some, such as the ocean kelps, bear a strong resemblance. Some of what we call algae are actually bacteria, while others live inside of microscopic animals, others in lichen, and still others branch out on their own. For our purposes, we'll treat them as a group, gauging their abundance by green-ness but not looking at any taxonomic diversity. What makes algae, and most plants, green is chlorophyll (it is also what allows them to trap sunlight and use it to create sugars). We took water samples from our pond and analyzed them for the content of chlorophyll and phaeopigments (Fig. 42). Phaeopigments are mostly rotten chlorophyll. While the presence of chlorophyll itself in a sample indicates the occurrence of living, chlorophyll-bearing organisms such as algae, phaeopigments indicate the past presence of such organisms. A pond which experienced an algal bloom and bust some time previous to sampling might have relatively little chlorophyll in its waters but quite a bit of phaeopigment.

Because algal abundance is thought to be a prime marker of eutrophication, a biologist named Carlson came up with a special number called "The Trophic State Index" (abbreviated TSI) which serves to give ponds a grade in terms of their relative state of eutrophication. TSI is calculated based on chlorophyll concentration and, since so many other researchers have used it, it gives us a handy number for comparing our findings to those of other biologists.[14]

First, let's just ask how our ponds stacked up in comparison to this generalized scale (Table 4). The value of the Trophic State Index increases with increasing nutrient enrichment. Other researchers, looking at a variety of characteristics, have come up with several classes of eutrophication. We've used six classes. Ponds in the first class are often termed "Oligotrophic" and are clear and nutrient poor; ponds in class 7 are "Hypereutrophic", excessively rich in nutrients and tend to be rich in algae and/or plants. Beginning around the fourth TSI class, ponds are reported to show definite signs of eutrophication (e.g., smells, algal blooms, reduced fish diversity). Almost 50% of the ponds we studied ranked as eutrophied (Table 4). In other words, nearly half were likely showing profound ecological effects due to excessive nutrient in-flow. Given that the vast majority of our ponds are relatively young, this degree of eutrophication cannot be attributed to natural processes. To put this in context, the degree of eutrophication in Columbia County ponds appeared to fall between that

Fig. 33. Crystal-clear waters are often our ideal. However, they are rarely natural in our setting. They are usually only found in recently-dug ponds such as this one or in ponds treated with algaecides. While herbivorous fish can control greening, they usually are evidenced by stirred up waters with a high sediment load.

Fig. 34 This seep-fed cattle watering hole shows both floating algae and submerged filamentous growth. Surrounded on three sides by forest and probably too small for fish, this pond supported high densities of Wood Frog and Salamander eggs many of which, judging by subsequent visits, hatched and continued to develop.

Fig. 35 A thick, frothy layer of algae, much of which may be dead and dying at a pig pond. Because pigs like water, they are often housed near ponds which can quickly become nutrient rich. Small isolated ponds such as this one may serve as nutrient traps, however locating pigs near running water may result in substantial down-stream nutrient increases.

Fig. 36 A thin, floating layer of greenery that opens and closes based on wind, currents and other disturbance, is usually a small flowering plant (Water Meal or one of the Duckweed species) rather than algae. Of course, these too are responding to the nutrients in ponds. Duckweed reportedly makes a good pig food and, as the name would imply, ducks do apparently eat it too.

Fig. 37 Many ponds develop a green fringe of floating algae. At least some of this may be bottom growth that has subsequently floated to the top and then been blown to the edges by the wind.

Fig. 38. Dense submerged water weeds grew in some ponds. In this case, our sediment coring efforts were somewhat tangled by such plants (that's our sediment corer resting on the paddle, its metal sheath still in place.

Fig. 39 Floating vegetation such as these water lilies can also green a pond's surface, and provide resting sites for frogs and dragonflies These lilies were relatively rare on our ponds.

Fig. 40 Some of the algae that eventually end up as a green surface scum, start out growing attached to the pond bottom. Eventually, much of it breaks free and floats to the surface. It is believed that such bottom growth is tapping nutrients stored in the sediments. However, in our sample, ponds supporting such growth were not particularly high in sediment nutrients. A shallow pond with a sunlit bottom is also needed for such growth.

Fig. 41 High concentrations of suspended algae can create this thick broth. While the nutrients supporting such a greening may come from adjacent land use and septic systems, they can also, in part, arrive naturally. This is a relatively old pond and probably has received a good dose of nutrients from the leaf fall of the surrounding forest

Figs. 42 To index chlorophyll and phaeopigments, we filled a syringe with pond water, attached to the hole at the top of the filter illustrated at left. After passing a known amount of pond water through the filter, we opened the filter (see image on right) and removed the filter paper for subsequent analysis. This filter came from a pond with high amounts of dissolved algae; if there had have been no algae, the paper would have been white.

TSI Value	Chlorophyll a (ug/L)	Attributes (from Carlson)	Columbia County, NY % of 92 ponds	Chester County, PA % of 13 ponds	MA (various counties) % of 24 ponds
<30	<0.95	Oligotrophy: Clear water, oxygen throughout the year in the hypolimnion	13	0	17
30-40	0.95-2.6	Hypolimnia of shallower lakes may become anoxic	27	0	42
40-50	2.6-7.3	Mesotrophy: Water moderately clear; increasing probability of hypolimnetic anoxia	18	8	25
50-60	7.3-20	Eutrophy: Anoxic hypolimnia, macrophyte problems possible	20	8	8
60-70	20-56	Blue-green algae dominate, algal scums and macrophyte problems	18	46	4
>70	>56	Greater densities of algae and macrophytes	3	38	4

Table 4. A description of the values of the Trophic State Index (TSI) relative to chlorophyll concentrations and the appearance of ponds. The columns on the right indicate how many of our ponds fell into each class; for comparison, we've also included data from eastern Pennsylvania and from Massachusetts. TSI is a re-expression of Chlorophyll concentrations and so the evident relationship between TSI and chlorophyll reflects mathematics and nothing deeper.[14]

of more urbanized eastern Pennsylvania and the collection of Massachusetts ponds.

In our data, is eutrophication clearly related to surrounding land use? Does it provide yet another example of the inter-connectedness of our landscape? At the top of the next page is another one of those mathematical table for you to mull over. In all fairness, we could have presented a variety of results to you. The details of the results depend in part on what factors one includes and some of the intricacies of how the model is run (see appendix for most details of each particular set of results). However, almost any way that we analyzed this, land in lawn and in ploughage came out as being significantly positively related to TSI. This pattern held true whether we used TSI or total pigments (chlorophyll plus phaeopigments).

Dependent Variable: **Trophic State Index**
% of Variation Explained by Model: **12%**
Number of Ponds in Analyses: **99**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Min. Distance to Forest	**-0.202**	**0.085**
% Lawn within 400'	**0.257**	**0.017**
% Plowed Land within 400'	**0.313**	**0.011**
% Hay within 400'	**0.205**	**0.051**

Let's look at Figure 43.

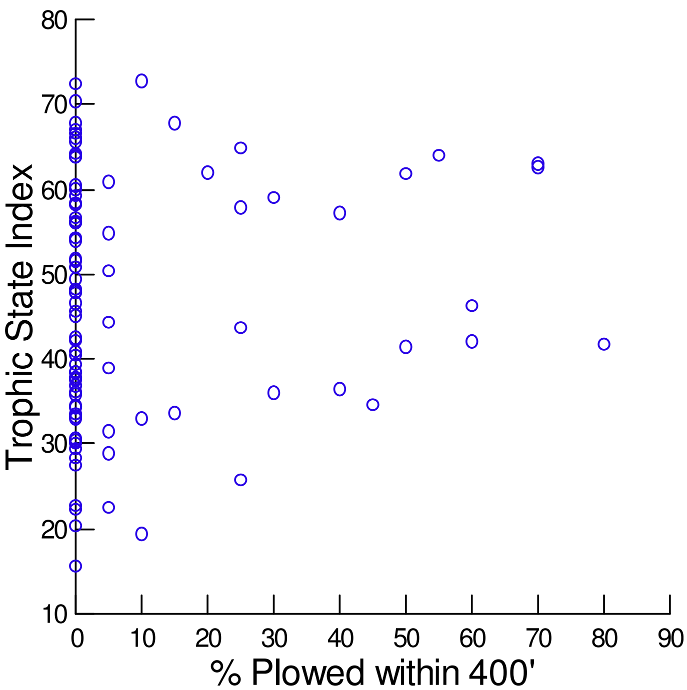

Fig. 43 The Trophic State Index (based on chlorophyll concentration) in relation to plowed land around the pond. TSI tended to increase with plowed land.

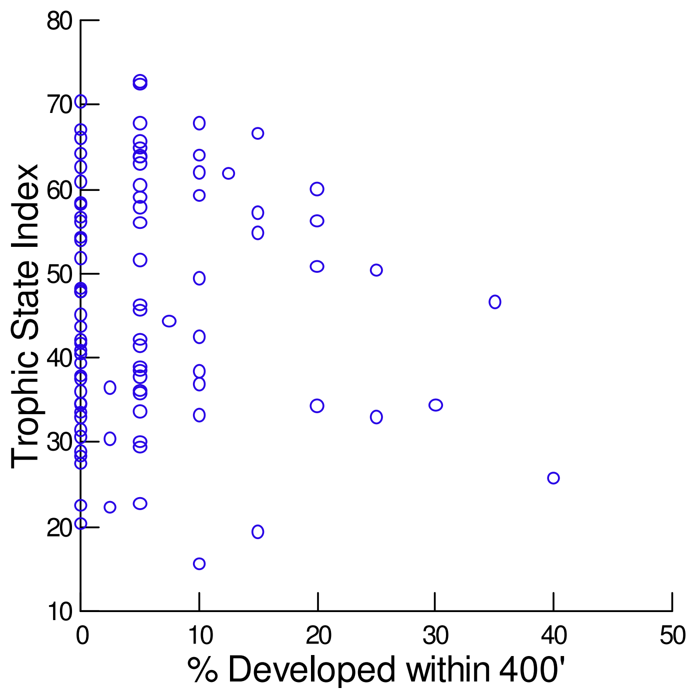

Fig. 44 Trophic State Index in relation to % developed area. The tendency is for TSI to decrease with increasing area in development, although, again, note how important the few higher values are in determining the shape of the apparent pattern.

There's a suggestion of a pattern. Certainly, for example, a high incidence of plowed land appears to be connected with higher than average TSI values. Both of these patterns have a ready explanation: lawn and field fertilizers are, together with sewage, thought to be one of the prime causes of pond eutrophication. However, what about the following Figure 44? TSI appears to be *negatively* related to degree of neighboring development, meaning that higher development is associated with lower eutrophication. This factor was not deemed significant by the model we presented above, but it flirted with significance in other models. Is this pattern real or just chance? Are the patterns above any more real?

We can't say for sure, but these figures raise questions for future studies and, certainly, the work of others supports the role of fertilizers in eutrophication.

All Photosynthetic Organisms – And the Green Growth Floats All Around: We'd like to leave eutrophication and move on to more charismatic subjects, but because eutrophication is such a central issue in the consideration of human effects on aquatic systems, we'll take one more look at it. Above, we indexed eutrophication by looking at algal growth measured on one date in the year. What about data from other times of the year and from higher plants? After all, anybody who owns a eutrophic pond knows that it can pass through a variety of colors and textures during the year, and that, furthermore, other green organisms, such as Duckweed and pond weed may also become abundant. We had data on estimated algal growth during May, total aquatic plant coverage from July and August botanical inventories, and Duckweed abundance during September (when TSI data was also collected). We indexed ponds by calculating the average relative amount of growth of each of these aspects of green-ness for each pond. We called this "Average Growth", and let's take one last look at eutrophication measured in this way before moving on. Here's a strikingly simple model that explains nearly a third of the variation in average growth (just to give you an idea of the predictive power, or lack thereof, of such a mathematical model, we've included Figure 45) :

Dependent Variable: **Average Aquatic Growth**
% of Variation Explained by Model: **31%**
Number of Ponds in Analyses: **88**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Fish Presence	**-0.260**	**0.006**
Lawn within 100'	**-0.325**	**0.001**
Woods within 400'	**-0.299**	**0.002**

Average growth decreased with the presence of fish in ponds (Fig. 46) and as lawn or neighboring forest increased (Fig. 47). The effects of fish on aquatic growth should not be surprising—after all, people often stock their ponds in order to reduce plant growth. We hope the effects of lawn are confusing, not because we want to confuse you, but because we just got done claiming that lawn (albeit within 400' not 100') was positively related to TSI. Chlorophyll measurements went into both TSI and our Average Growth variable, so how could there be opposite relationships? Ecologically, we can't explain it, but mathematically perhaps we can dissect it. Because Average Aquatic Growth is a composite of the four variables mentioned above, it should only be negatively related to lawn if at least one of the factors other than TSI is strongly, negatively related to lawn. In fact, all three remaining components of Average Aquatic Growth (i.e., May algal growth, summer aquatic plants, and autumn duckweed) were negatively related to lawn; with aquatic plants and duckweed showing the strongest relationships.

Another possible source of confusion is that all the habitat variables were intercorrelated. For example, a pond surrounded by 80% lawn could not be surrounded by more than 20% woods. In the above analyses, plowed and pasture land were also related to aquatic growth, albeit not as strongly as lawn and woods. In effect, lawn may represent more than just lawn.

To get around this problem of intercorrelation, we conducted a principal component analysis similar to what we did with the sediments, only this time, instead of entering sediment elemental concentrations, we entered

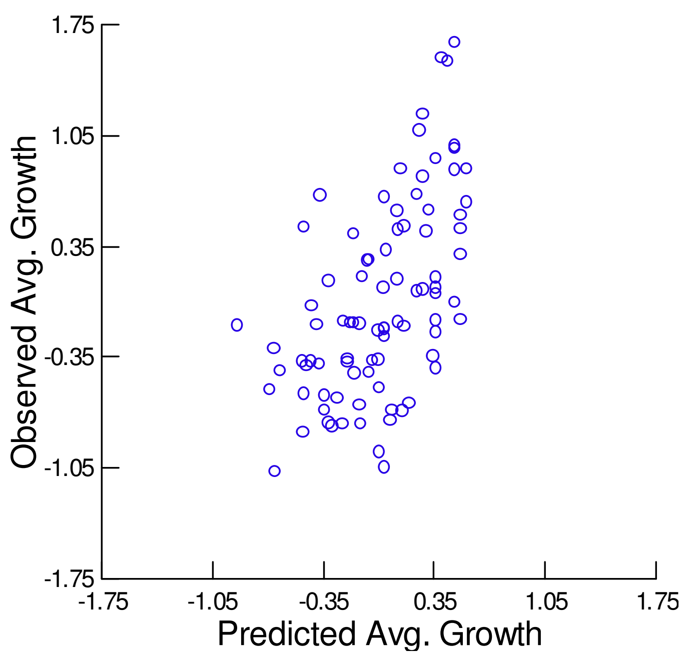

Fig. 45. Predicted average aquatic growth vs. observed values. Clearly, there is a relationship; clearly, there's still a lot of variation left to explain.

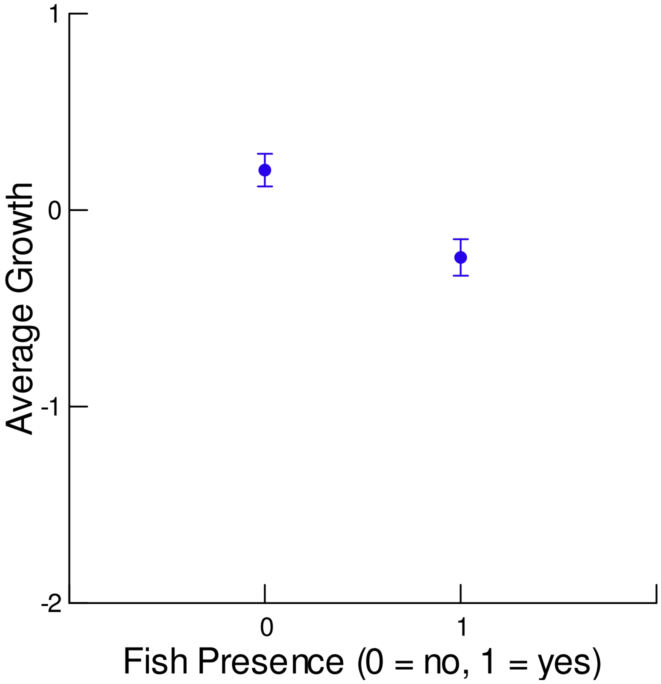

Fig. 46. The effect of fish presence on aquatic growth. Aquatic growth was lower in ponds where fish were present.

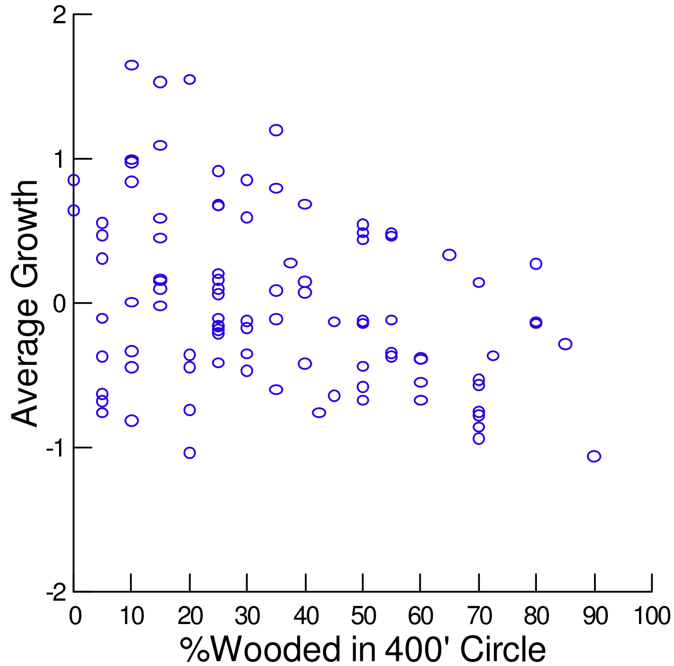

Fig. 47. The relation between average aquatic growth and % of woodland in the surroundings. As forest increased, aquatic growth tended to decline.

our land use data. This resulted in six different habitat "menus" that were completely independent of each other (the mathematical process assures that). While these are not as easy to interpret as variables like "% plowed land", they are more valid ingredients in our modeling soup because they represent themselves and not anybody else. We won't tire you with the details of our habitat components (details are in the appendix), however, we will tell you that among six components, one represented, more or less, plowed land, another forested land, and another was heavy on the lawn. The lawn and forested factors were strongly correlated with Average Growth, whereas only the plowed land factor was related, and then only weakly, to TSI. From this, we conclude that there was good evidence of a negative relationship between Average Growth and both forest and lawn, but that the patterns surrounding TSI were less clear, although there was a hint that plowed land contributed to chlorophyll concentrations. We wish it were more clear, but wishing doesn't make it so.

Interestingly, in our nod to Liebig, sediment phosphorus showed no relation with either TSI or average growth. Based on published studies of eutrophication, we had suggested a link between sediment phosphorus and pond green-ness. However, this was not evident in our ponds. The seven sediment components which we identified earlier also did not show any substantial relationship to our eutrophication variables.

We'll move on to some more appealing characters than green pond slime: flowering plants, fluttering butterflies, mosquito-eating dragonflies, and croaking frogs. Aside from giving you a glimpse of some of the attractive diversity in each group, we'll take much the same analytical approach as we did with the aspects we have already considered. We will ask what landscape factors correlated with, for example, amphibian diversity. We will also return to some of our measures of eutrophication (e.g., TSI, Average Growth) and our sediment components to see what, if any, effects they might be having on the rest of the biota.

Eutrophication is an ecological consequence of a pond's nutrient enrichment. These nutrients (e.g., phosphorus and nitrogen) encourage the growth of algae or higher plants. In our data, the growth of such organisms was not directly related to sediment phosphorus, although it showed some correlation with surrounding land use, specifically it decreased as lawn or forest increased. The presence of fish in the ponds correlated with reduction in our measure of total green growth.

VASCULAR PLANTS

Ponds are interesting places for plant diversity, because they offer habitat for three groups of plants: aquatic plants that live submerged or floating in the water itself; wetland plants, rooted in shallow water or in wet soil along the shore and emerging from the water; and upland plants that are quite intolerant of "wet feet" but often grow right to a pond's edge if the bank is well drained. As a consequence of this range of conditions, in our surveys of 89 ponds we found a total of 369 plant species growing either in the water or along the shore within approx. 1 m from the water's edge. We visited each pond once in the period from June through September and attempted complete inventories of all the vascular species (flowering plants and ferns, but not mosses) present at the time of visit. The abundance of each species was ranked in the following four classes: rare (1-2 individuals seen), uncommon (few individuals seen, or species occurring in a few small patches), common (occurs throughout but is well interspersed with other species), and abundant (tends to dominate vegetation at least in some larger patches). A listing of all the plants documented at the ponds is available upon request.[15]

The following table gives an overview of the composition of the pond flora.

	Total No. in Given Class	No. of Native Species	No. of Species of Conservation Interest[1)]	No. of Invasive Species[2)]
Total Number of Plant Species	369	259	25	25
Number of Wetland Species	158	140	10	8
Number of Aquatic Species	41	34	3	4
Number of Upland Species	170	85	12	13

1) Species of Conservation Interest are either state-protected species or species recognized as regionally rare or scarce by Hudsonia.[6]
2) Invasive Species as defined by the Invasive Plant Atlas of New England.[16]

Table 5. Summary of the composition of the pond flora of 89 study ponds in Columbia County.

Of the 369 species, 11% were aquatic plants, 43% wetland plants, and 46% upland species. Of the total number of recorded species, 70% were native to our region. This last value is very similar to the percentage for Columbia County as whole and in the flora of the entire State of New York, which are both composed of 67% native plants. The percentage of native species was highest among the aquatic plants (83%) and the wetland plants (89%). However, both of these more pristine groups of plants did have a number of invasives in their midst.[16]

The most frequently encountered species (found at more than 50% of the study ponds) were Rice Cut-grass, Spotted Jewelweed, Waterpepper, Sensitive Fern, Arrow-leaved Tearthumb, Purple Loosestrife, Common Water Purslane and Soft Rush. We looked at the frequency of occurrence in our study ponds for each species: more than 100 species were documented at only one pond; the average number of plant species recorded from a pond was 35; and the maximum from any one pond was 84.

Species of conservation interest found at the ponds included the state-protected Winterberry, Flowering Dogwood, Turtlehead, Cardinal Flower, Nodding Lady's Tresses (an orchid!), several fern species and the aquatic plants Spiny Coontail and Hill's Pondweed, as well as the regionally rare or scarce Whorled Milkwort, Blue Cohosh, Green-headed Coneflower, Great Solomon's Seal, Silky and possibly Prairie Willow, Halbert-leaved Tearthumb, Mountain Maple, Giant Ragweed, and several grass and sedge species.

Doubtless, the upland species growing around the shores of ponds contribute to the overall diversity of a pond's life. However, we found little reason to believe that the characteristics of the pond have much of an influence on the composition of the surrounding upland vegetation. Therefore, we focus on the aquatic and wetland plants of the ponds during the following analyses of the relationships between pond vegetation and pond characteristics, surrounding landscape, and other life forms in and around the pond.

Native Wetland Plants – A Foot in Both Camps: As the regression table below indicates, the total number of native wetland plant species of a pond was positively correlated with the amount of wetland area in the surroundings (Fig. 48) and with water depth in the pond, but negatively correlated with the proportion of developed land within 100m of the pond (Fig. 49).

Dependent Variable: **Number of Native Wetland Species**
% of Variation Explained by Model: **21%**
Number of Ponds in Analyses: **83**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Abundance of Nearby Wetland	**0.268**	**0.012**
% Developed within 100'	**-0.269**	**0.011**
Pond Depth	**0.239**	**0.026**

Therefore, characteristics of both the pond itself as well as the surrounding landscape, significantly correlate with the species diversity of native wetland plants. A pond embedded in a larger wetland area is likely to have a larger number of native wetland plants growing in and immediately around it, than a pond of otherwise similar characteristics, but located within an upland surrounding. Ecological reasons for this pattern might be the ease of arrival of plant propagules (e.g., seeds) and the advantages for a plant to be part of a larger

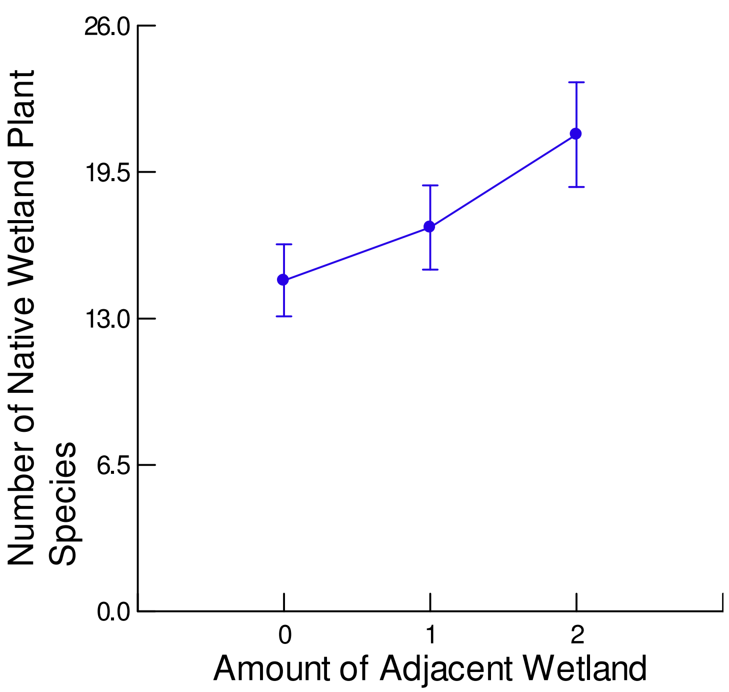

Fig. 48. The number of native wetland plant species around each pond in relation to the amount of wetland adjacent to the pond. More wetland, more wetland plant diversity.

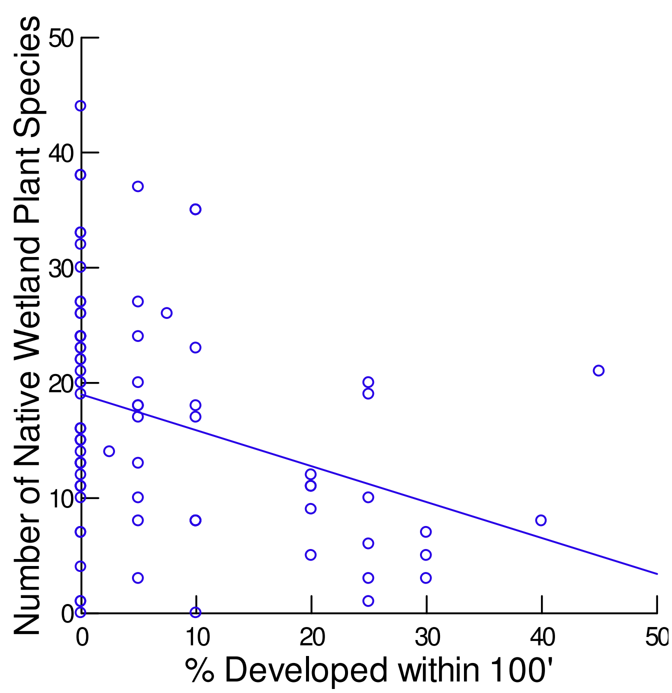

Fig. 49. The number of native wetland plant species in relation to developed area within 100' of a pond. Diversity reached its highest levels in ponds where development was lowest.

Fig. 50. Grass of Parnassus. A calcicole (i.e., limestone-loving) species often associated with other rare plants.

Fig. 51. Sweet Flag. Another species of calcareous wet meadows.

Fig. 52. Turtlehead. One of the more common wetland flowers; an important food plant for the Baltimore Checkerspot Butterfly.

Fig. 53. Yellow Star Grass. This flower is not a grass, but rather a small, wild relative of the daffodils; it is occasionally found in wet meadows.

Fig. 54. Nodding Lady's Tresses. We found this native orchid in the vicinity of two study ponds.

Fig. 55. Halbert-Leaved Tear-Thumb. This Tear-Thumb is much rarer than Arrow-leafed Tear-Thumb; both are wetland species.

Fig. 56. Cardinal Flower. This state-protected wetland plant was found only once in our study. It was growing around the shore of a pond and along its outflow. Hummingbirds favor this flower.

Fig. 57. Lobelia. This rare relative of the Cardinal Flower was also found at only a single site—a wet meadow near one of our study ponds.

population (e.g., to avoid inbreeding). Similarly, a pond embedded in a larger undeveloped area is likely to harbor more native wetland species than a pond in the immediate vicinity of development. Pond depth might be a positive factor for native wetland species diversity because the pond and its surrounding wetland vegetation are better buffered from the effects of drought than a shallow pool that might periodically dry out. In one set of regression models, the presence of fish was found to be highly correlated with wetland plant diversity, however we believe that this result was probably due to a correlation of fish presence with pond depth and with adjacent wetland.

Invasive Wetland Plants – Looking for the Sweet Life: The diversity of native plants is one indicator of the "health" or "degree of naturalness" of a plant community. Another indicator is the absence or small number of invasive plant species. We found eight species of invasive wetland plants at the study ponds, the most frequently observed were Purple Loosestrife (52% of ponds), Reed Canary Grass (45%), Bittersweet Nightshade (31%), and Common Reed (20%). Here's the correlation table:

Dependent Variable: **Number of Wetland Invasive Species**
% of Variation Explained by Model: **44%**
Number of Ponds in Analyses: **80**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Soil Calcareous Class	**0.252**	**0.009**
Minimum Distance to Paved Road	**-0.286**	**0.002**
% Pasture in 400' Circle	**-0.338**	**<.001**
Pond Age (Square Root)	**0.259**	**0.006**
Pond Water pH	**0.219**	**0.019**

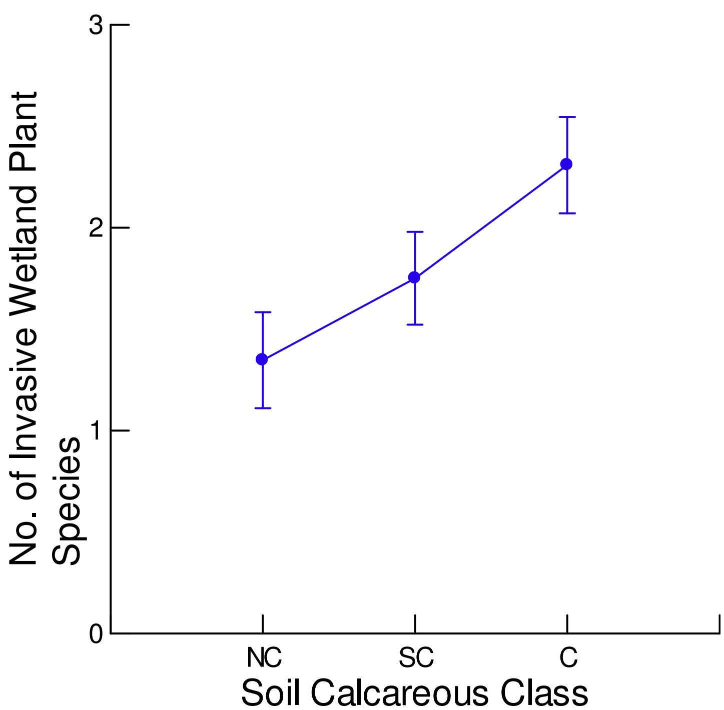

Fig. 58. Number of invasive wetland plant species compared to soil calcareous class (based on Columbia County Soil Survey as classified by Hudsonia[6]). More calcareous sites tended to have more invasives. NC = Not Calcareous, SC = Somewhat Calcareous, C = Calcareous.

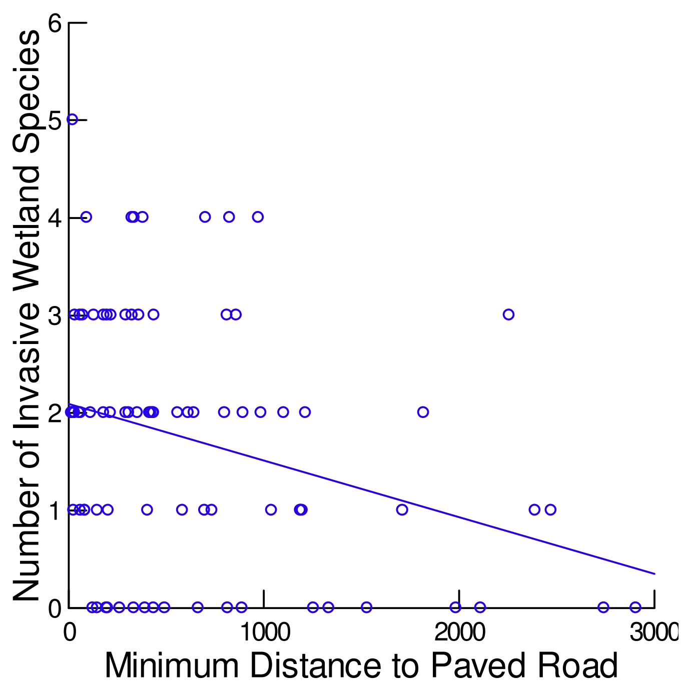

Fig. 59. The number of wetland invasive species versus the distance to the nearest road. Invasive species tended to be most common when roads were nearby.

The number of invasive wetland plants was significantly negatively correlated with the distance to the nearest paved road (the further away the nearest paved road, the fewer invasive species) and with the amount of pasture in the vicinity of the pond (the more pasture land, the fewer invasive species). In general, ponds with more non-agricultural development in their vicinity, tended to have a higher number of invasive wetland species. This correlation might reflect a direct cause-effect relationship, where more non-agricultural development increases the likelihood that propagules of invasive species arrive at the pond, either through escape from ornamental gardens (e.g., Purple Loosestrife) or through spread along roads/road-side ditches. Furthermore, development and its associated impacts (e.g., runoff from roads and lawns, leaking septic systems) might benefit invasive over native wetland species.

Aside from the surrounding landscape factors, the number of invasive wetland species was also significantly correlated with the pH of both the pond water (measured directly) and the underlying soil type (as derived from the Columbia County Soil Survey and classified according to pH by Hudsonia). Calcareous soils and more alkaline waters tended to support more invasive wetland species. Examining the distribution patterns of the four most common invasive wetland species, three showed a clear preference for calcareous conditions: Common Reed, Purple Loosestrife and Reed Canary Grass. They occurred on 30%, 70% and 52% , respectively, of the ponds on calcareous or potentially calcareous soils, while being found around only 7%, 32% and 36% of the non-calcareous ponds.

Native Aquatic Plants – The Older, The Better: The diversity of native aquatic plants (for our purposes defined as submerged or floating) in the ponds was also significantly positively correlated with the amount of surrounding wetland area as the following regression table indicates:

Dependent Variable: **Number of Native Aquatic Species**
% of Variation Explained by Model: **27%**
Number of Ponds in Analyses: **81**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Pond Age (Square Root)	**0.315**	**0.002**
Abundance of Nearby Wetland	**0.355**	**0.001**

Again, ponds embedded in larger wetland areas might be more likely to support a diverse aquatic flora because the plant propagules are easily dispersed into the pond from the surrounding populations. Furthermore, aquatic plant diversity was significantly higher in older ponds. This may have been due to the accumulation of species over time and/or diversity-favoring, ecological characteristics in older ponds.

Invasive Aquatic Plants – Wanting BOB (Big, Open & Basic): We found four invasive aquatic species in our study ponds. Eutrophic Waternymph occurred in eleven ponds, Curly Pondweed in six, Water Chestnut in five, and European Water-milfoil in two ponds of the 89 ponds. As the regression table on the next page indicates, the number of invasive aquatic species was positively correlated with pond size and the distance of the pond from large forest patches, as well as water pH and alkaline sediments (Fig. 61). Examining the distribution of each of these invasive species individually, Curly Pondweed

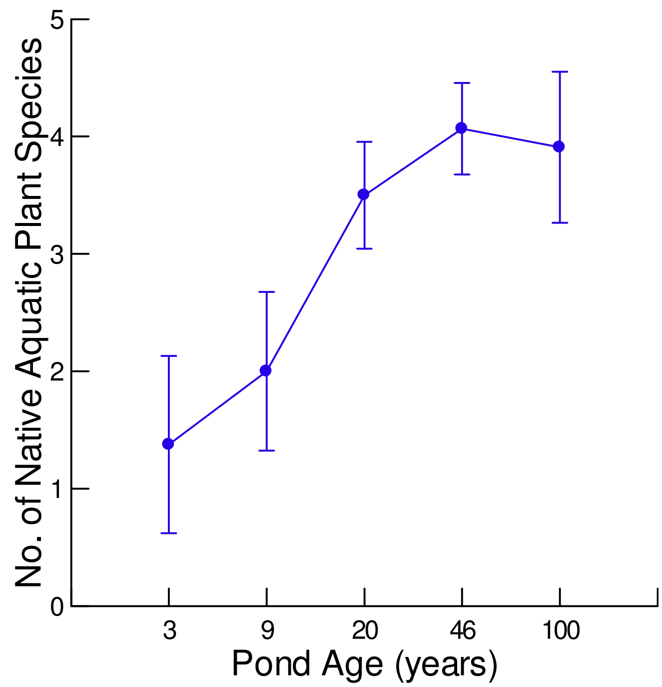

Fig. 60. The estimated age of a pond vs. the diversity of native aquatic plants. Older ponds were more diverse.

Dependent Variable: **Number of Aquatic Invasive Species**
% of Variation Explained by Model: **42%**
Number of Ponds in Analyses: **71**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Pond Area	**0.320**	**0.002**
Minimum Distance to Forest	**0.213**	**0.029**
Pond Water pH	**0.245**	**0.036**
Sediment Component 2	**0.267**	**0.016**

showed a very clear preference for high pH. We did not find it in any of the 65 ponds with a water pH lower than 8, but it did occur in four of the 16 ponds with a pH of 8 or higher.

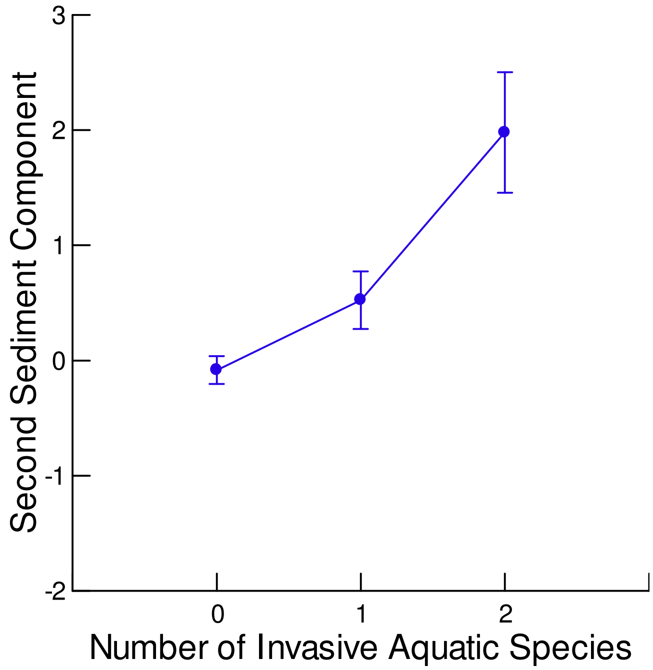

Fig. 61. The value of the second sediment component (this component represents the sediments typical of high pH (or "alkaline") ponds. Note that because there were so few values for invasive aquatics, the dependent variable is, uncharacteristically, shown on the x-axis.

Interactions of Pond Plants with Animal Life: As will be mentioned in the section on amphibians, the shelter provided by plants growing in and around ponds becomes important for frogs and salamanders especially in those ponds where predatory fish are present. We have no reason to expect the species diversity or composition of that vegetation to be of any importance, as long as its structural characteristics provide good hiding places for both tadpoles and adults.

Butterflies depend on plants both as adults, with nectar as their main source of food and as larvae, with most caterpillars eating leaves. Adults tend to drink nectar from a wide range of flowering plant species, taking advantage of whatever is available. A place with a diversity of plants offering plenty of nectar throughout the season will usually be found and frequented by the highly mobile butterflies, at least within the regional context of Columbia County. The story is very different, however, for their caterpillars, which often depend on a very small number of host species . Some of our regionally rare, wetland butterfly species, such as Baltimore Checkerspot, Eyed Brown, Bronze Copper, Black Dash, Mulberry Wing, and Broadwing Skipper, lay their eggs mostly or exclusively on wetland plants and depend on these plants for the successful rearing of the next generation. However, our observations of these rare butterflies where too scant and some of their food plants too wide spread to show any significant correlation between the occurrence of the butterflies and their respective food plants.[17]

We found 369 species of plants in or around our ponds; 270 of these were native. The diversity of native aquatic and wetland plants were positively correlated with the abundance of nearby wetlands. Invasive wetland and aquatic species were both favored by higher pH of soil and water. Furthermore, invasive wetland species became more diverse in the vicinity of roads, and invasive aquatic species became more diverse with increasing distance from forest.

AMPHIBIANS – VOCAL HERALDS OF CHANGE

Most frogs (fig. 62) and salamanders rely upon water bodies for at least part of their life cycle. While some of these favor streams, many breed in ponds. We tallied ten different species in the ponds we studied (Table 6), although the number at any one location ranged from zero to eight. Some species, such as Wood Frogs, Tree Frogs, Spring Peepers, and Mole Salamanders (*Ambystoma* spp.), spend much of their adult lives in upland areas that may be relatively far from water, but then return to ponds to breed and lay eggs (Figs. 63, 64, 66-68). The adults of other species (Red Spotted Newts, Bull Frogs, Green Frogs, Leopard Frogs and Pickerel Frogs) are less apt to stray from wetlands. Many species metamorphose the same summer that they hatch, however at least a couple of species (Green Frog and Bull Frog) may remain as aquatic larvae for a year or more. In a regionally unique life history pattern, the "punk" teenagers of the Red Spotted Newt, i.e., the Red Eft, wander widely (as most local hikers know) before the adults return to an aquatic life style.[18]

Fig. 62. A Leopard Frog. This was our rarest amphibian, it was found on only one farm. Interestingly, it appears to be relatively common farther west in the State, but in those locations the Pickerel Frog is apparently scarcer than here.

Few residents of our wetlands are better known or, at least during some times of the year, more conspicuous than our frogs. The worldwide decline in frogs has received substantial attention of late. The immediate causes of this decline seem diverse, although they may all ultimately reflect increased environmental stress. While we don't have the historical data to look rigorously at frog decline, we can look for current factors that might be affecting amphibian occurrence in our landscape.[19]

We surveyed most frogs by following the Frogwatch protocol. This method involves listening for frogs on warm nights after sunset (that may sound romantic, but it got rather buggy). All of our region's frogs call as a way of attracting mates and establishing territories. Their calls are, with a little practice, distinguishable, and we tried to visit each pond three times during the summer to record species heard and the intensity of their calls on a scale of 1 to 3.[20]

Amphibian Species	% of 93 Ponds Where Found
Green Frog	89
Spring Peeper	55
Bull Frog	42
Grey Tree Frog	42
Spotted Salamander	41
Red-spotted Newt	31
Wood Frog	29
Pickerel Frog	27
American Toad	15
Leopard Frog	2

Table 6. The occurrence of amphibians at the 93 ponds which we surveyed. Based on egg mass size and location, we believe that Jefferson/Blue-spotted Salamanders were also present, but we did not tally them.

Salamanders, including newts, do not call, and the Wood Frog has only a very brief, early-spring calling period. We surveyed for these species visually, counting egg clusters in the case of Spotted Salamanders, Jefferson Salamanders, and Wood Frogs, and tallying adults in the case of Red Spotted Newts. We standardized our visual counts by length of pond bank inspected.

While we believe that this methodology provided a fairly complete description of each pond's amphibian fauna, certain species (e.g., Marble Salamanders) would not have been detected by this method, and we have no doubt that in some cases the rarer species eluded our counts.

The Green Frog was by far our most common species. This frog is a widespread generalist, found in ponds and along creeks. Our least common was the Leopard Frog – it was found at two sites on a single farm. American Toad was also relatively uncommon, however we think that this may be partially due to its relatively brief breeding period, its somewhat inconspicuous

Fig. 63. Pickerel Frog eggs. These are found in tight clusters the size of a small grapefruit. Eggs are surrounded by relatively little jelly compared to those of wood frogs. The developing embryo is distinctly bicolor.

Fig. 64. A diverse set of amphibian eggs. Pickerel Frog eggs are the darker clusters; the looser, lighter clusters that are nearer the surface appear to be from Wood Frog with some cloudier salamander egg clusters evident in deeper water.

eggs and the fact that, during breeding, it seems to cluster more intensively than some other species. Generally speaking, American Toads have not been an unusual sight in our region. Other amphibians occur in Columbia County, but either favor different habitats (e.g., stream salamanders) or, like the Marbled Salamander, were not "caught" by our survey techniques.

Our prime measure of amphibian species abundance (average frog calling intensity) was very highly correlated with amphibian diversity (Fig. 65). This suggests that, not surprisingly, those areas providing good habitat for any one species, usually were beneficial for a range of species. Given the close relationship between these two variables, it would not be correct to treat these as two separate measures. Therefore we estimated the overall amphibian abundance for each pond by summing the relative abundance of each species including those censused visually. More diverse ponds had more apples in the barrel, ponds with higher abundance had heavier apples. Either way, the weight of the barrel increased, and "total amphibian abundance" is our measure of the weight of the barrel.

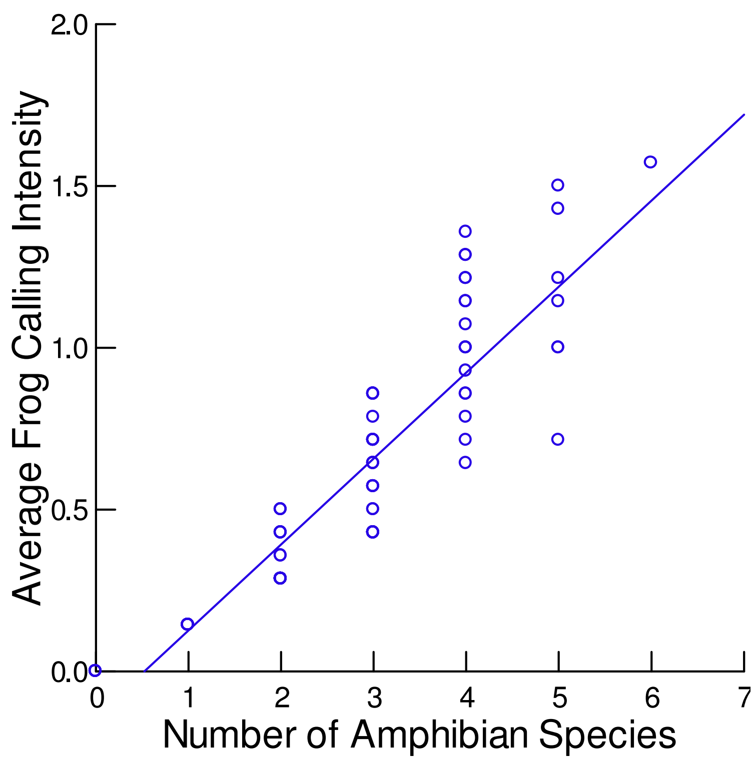

Fig. 65. The number of amphibian species at a given pond vs. the abundance of amphibians as indexed by frog-calling intensity. Diverse ponds not only tended to have more species but also more individuals.

As the regression table on the next page indicates, we looked at the factors which were correlated with Total Amphibian Abundance. The pattern seems relatively strong (nearly a third of the variation predicted) and the interpretation relatively straightforward. We've introduced one of our habitat menus here because this ecological investigation would get too contorted if we had to constantly hedge our remarks by discussing the intercorrelatedness of habitat characteristics. The habitat

Fig. 66 A Red-Spotted Newt checks out a cluster of Wood Frog eggs. These newts will prey upon such eggs.

Fig. 67. Mole Salamander eggs, probably Spotted Salamander, although a small cluster might also be Jefferson/ Blue Spotted. Spotted Salamander egg clusters are frequently surrounded by an opaque jelly resembling cooked egg white, rather than the clear jelly evident in this photograph. The eggs generally remain healthy.

Dependent Variable: **Total Amphibian Abundance**

% of Variation Explained by Model: **36%**

Number of Ponds in Analyses: **86**

Significant Variable	Standardized Coefficient	"Significance" of Effect
First Habitat Component	**-0.409**	**0.000**
Average Aquatic Growth	**0.251**	**0.007**
Size of Pond	**0.237**	**0.009**
Abundance of Nearby Wetland	**0.192**	**0.038**

component that entered, and entered strongly, was the one associated with widespread non-agricultural development. To use a term from our gastronomic explanation of principal components, it indicated a "diet" high in developed land, houses and roads. Amphibian abundance showed a clear, negative relation to this factor, meaning that the more residential or commercial development there was, the lower the amphibian abundance (Fig. 69). This relationship was echoed in the pattern of total amphibian abundance relative to land use categories (Fig. 70).

Three other pond characteristics were related to amphibian abundance: pond size (larger ponds meant more amphibians, even though we attempted to control pond size in some of our abundance measurements), average growth of algae and aquatic plants (more growth led to more amphibians), and the extent of adjacent wetland (more adjacent wetland, more amphibians; we'll see this factor again!). None of these

Fig. 68. A mating pair of American Toads in a farm pond.

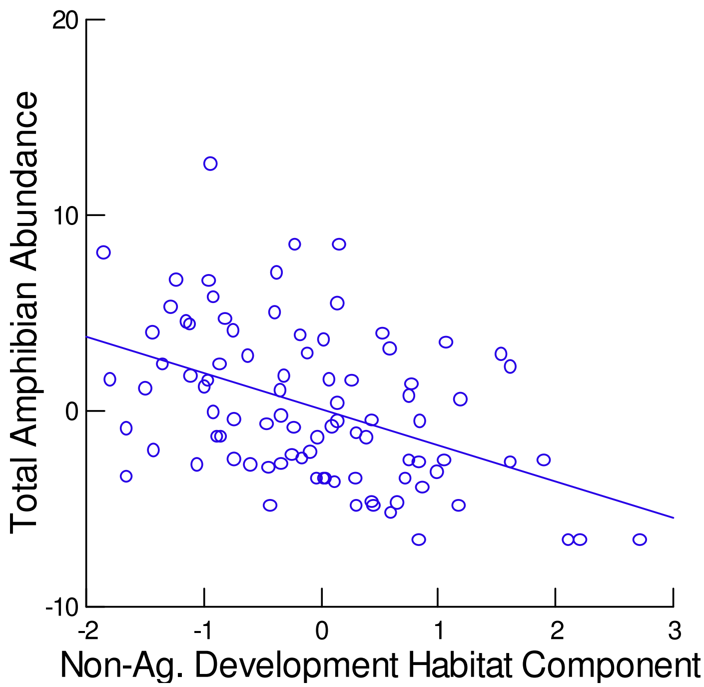

Fig. 69. The relationship between non-agricultural development (our first habitat component) and total amphibian abundance. Higher levels of development were associated with lower abundances.

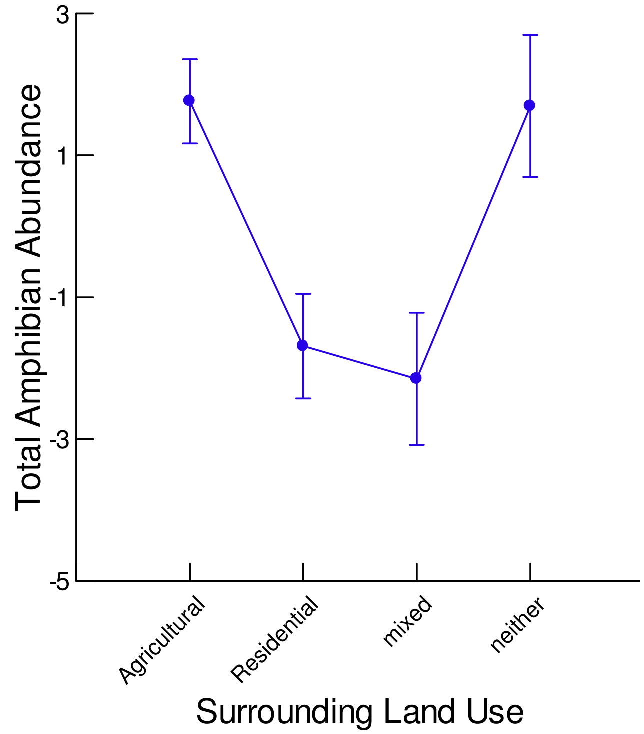

Fig. 70. Amphibian abundance and a classification of the land use context around each pond. Abundances were highest in ponds located in agricultural settings or where there was neither agricultural nor residential use.

relationships is surprising. Apparently, the degree of vegetative growth in our ponds generally benefited amphibians more than it harmed them. Aside from providing food for some larvae, vegetation also provides shelter from predators. Others have suggested that vegetation may help shelter amphibians from predators. We therefore compared the relationship of total amphibian diversity with and without fish to our classification of shoreline vegetation (Figs. 71 and 72). The resulting patterns showed elevated amphibian abundances with increased shoreline vegetation only when fish were present. This supports the notion that such vegetation provides meaningful shelter from predators.

How did each amphibian species fare? While we won't try your patience by profiling the patterns associated with each species, we do want to highlight a few patterns that may help you understand a bit more about pond ecology. Of the nine amphibian species for which we had adequate data, the abundances of six species (Wood Frog, Spotted Salamander, Newt, Spring Peeper, Pickerel Frog and American Toad) were negatively related to non-agricultural development, while that of three (Bull Frog, Green Frog, Tree Frog) showed no pattern. Half of the negative relationships were considered statistically significant. Fish presence was associated with decreased abundance of Wood Frogs and Tree Frogs. Sediment effects were less clear. Only Spring Peepers and Spotted Salamanders were significantly negatively related to sediments that regularly exceeded ecological effect standards, although Tree Frog, Green Frog and Wood Frog showed similar tendencies.

We looked at one group, vernal pool amphibians in a bit more detail. These are the species which spend much of the year in forests, coming down only briefly to breed in neighboring ponds. As we mentioned earlier, these are species which require not only healthy ponds but healthy uplands. Several authors have shown that the occurrence of vernal pool species is determined, in part, by the presence of adequate upland habitat in the surroundings. We pooled (forgive the pun) Wood Frog and Spotted Salamander abundances to come up with a single index of vernal pool amphibian abundance, we then asked how that related to neighboring woods (Fig. 73). Obviously, woods aren't the only thing that these critters need (indeed, fish absence was another key ingredient in statistical models), yet without forest, these species were not common.[21]

In sum, amphibians show more pronounced correlations with the nature of the surrounding land than did

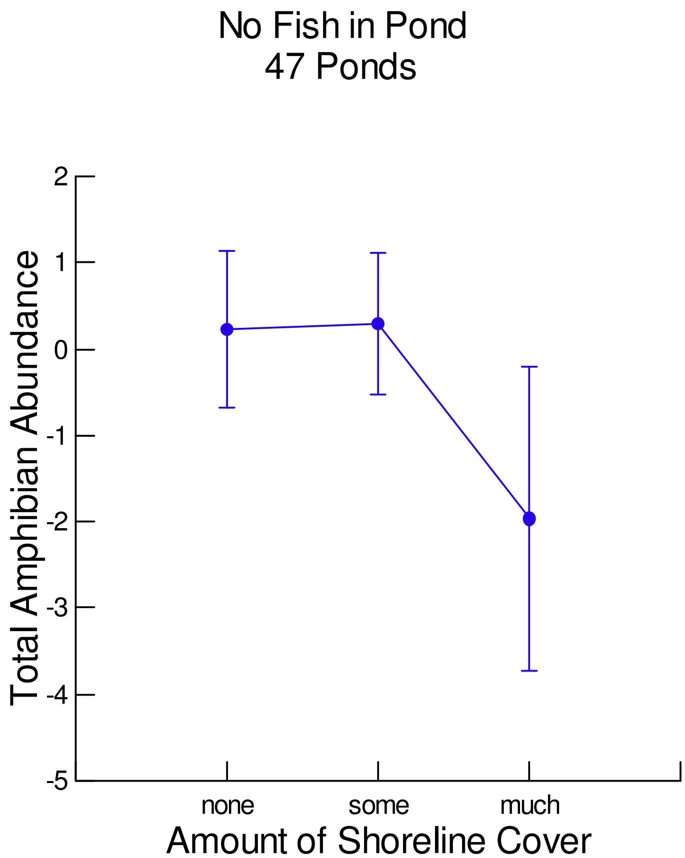

Fig. 71. The relation between shoreline vegetative cover and amphibian abundance *__in the absence of fish__*. *If anything, amphibian abundance was lower in ponds with much cover.*

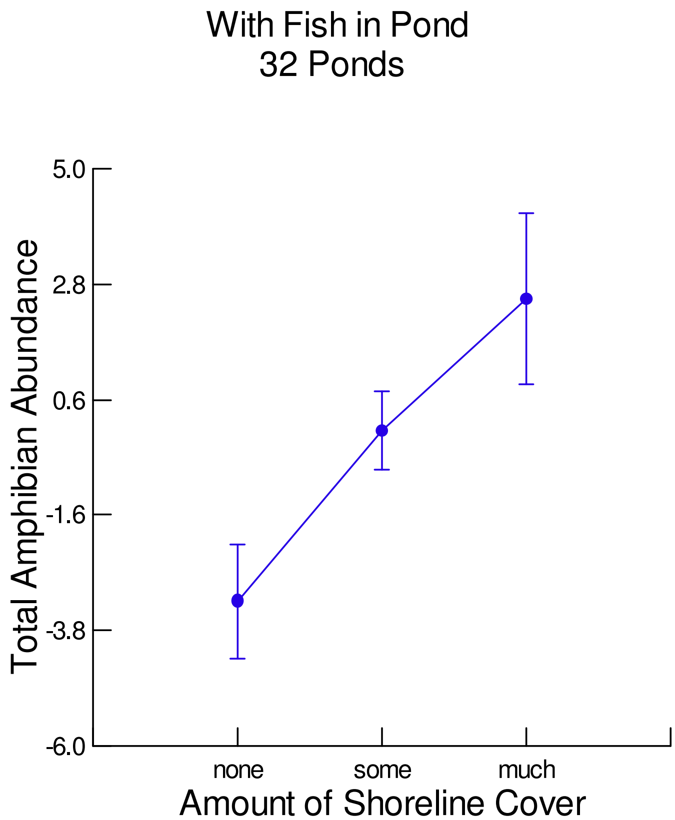

Fig. 72. The relation between shoreline vegetative cover and amphibian abundance *__in the presence of fish__*. *Amphibian abundance appeared to increase with increasing shoreline cover.*

either pond chemistry or eutrophication measures. This shouldn't be surprising, given that most of these species must actually live part of their lives in that landscape. These results emphasize the importance of thinking in landscape terms when conserving amphibians. The possible relationship to sediment toxicity is worrisome – some of the toxins in our sediments may be due to atmospheric deposition. If so and if some amphibians are affected by that deposition, then their conservation would require more wide-ranging changes than "simple" habitat management. Consideration of our own health should have already told us that (the EU, for example, estimates that air pollution shortens the lives of its citizens by an average of eight months).[22]

> *We found at least 10 species of amphibians in our ponds. Their occurrence was extensively correlated with habitat and landscape conditions. Non-agricultural development had a strong, negative effect on overall amphibian abundance. Density of shoreline vegetation was positively related to total amphibian abundance, but only in the presence of fish. Vernal pool amphibians tended to be most common in ponds near forest.*

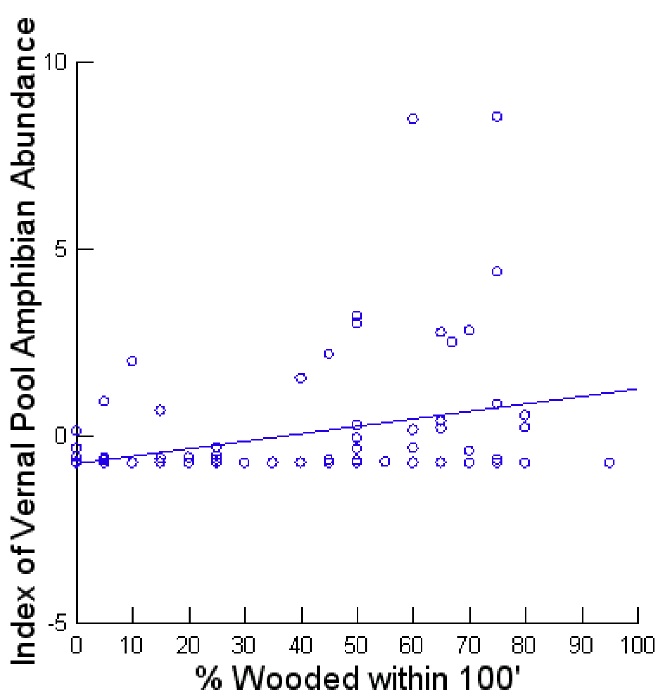

Fig. 73. The abundance of vernal pool amphibians in relation to extent of nearby woods. These species depend on wooded uplands during most of the year; their eggs appeared to be most common in ponds with abundant adjacent woods.

DRAGONFLIES & DAMSELFLIES – OF WATER AND AIR

Odonates (the name taxonomists have given to this group) have aquatic larvae. As such, adults are found around ponds as they emerge from the water and when they return to breed. (See Figs. 74-77 for illustrations of some local odonates.) Aquatic invertebrates have, in general, been widely used to evaluate the quality of aquatic habitats, although this has been more extensively applied to streams than ponds.

We surveyed adult odonates visually. Because our goal was to list all species flying during our visits, and because ponds varied in characteristics, we used variable length surveys and then standardized counts based on duration. For the most part, we followed the New York State Odonate Survey's protocol. Species which required close inspection were captured with a net and their wings were "pinned" to a magnetic board for photographing and inspection. Although a few specimens were kept for definitive identification, most were released after inspection. By the time the surveys were nearing completion, almost all species could be readily identified on the wing, and capture was generally not necessary. (One soon learned, for example, that the "snitches" were Eastern Amberwings, while the Jumbo Jets were usually darners of some flavor.)[23]

Different species of dragonfly and damsel have different flight seasons. Although we tallied all species that we saw during our surveys, only those species flying for most or all of our June – early September survey period were included in our statistical analyses. The timing of dragonfly surveys can also affect the abundance registered. Not only does hour of the day matter, but weather also determines how many dragonflies are flying. Our logistics did not allow us to take these considerations fully into account, although the majority of surveys were done between 10:00 am and 4:00 pm on rainless days between early June and late August. At the least, we have no reason to believe the effect of time and weather was other than random.

We found 47 species of dragonflies and damselflies during our surveys (Table 7). This is probably around a third of all dragonfly species that occur in the region. It is also a can of worms. How does one look for patterns in such diversity? We would probably not have any readers left were we to try to take you through a species by species analysis of occurrence. The compromise, aside from looking at total dragonfly abundance in the same way that we looked at amphibian abundance, is to look at the fate of a subset of these insects. Speaking broadly, pond odonates can be classified as generalists and specialists. Some species occur in a wide variety of pond types and even in certain flowing waters; others have more restricted distributions, occurring mainly in temporary ponds or marshy

Occurrence of Dragonflies and Damselflies Columbia County Ponds (89 ponds visited)

Species	% of Ponds Where Found	
fragile forktail	81	
eastern forktail	78	
red meadowhawk	62	
slender spreadwing	53	
eastern pondhawk	52	
blue dasher	44	
widow skimmer	42	
12-spotted skimmer	39	
common whitetail	36	
variable dancer	28	
azure bluet	25	s
common green darner	24	
eastern amberwing	24	
slatey skimmer	18	
familiar bluet	17	
black saddlebags	16	
orange bluet	16	
undet'd darner	12	
spotted spreadwing	10	
sedge sprite	9	s
dot-tailed white face	8	s
skimming bluet	8	
sweetflag spreadwing	8	
halloween pennant	7	s
band-winged meadowhawk	7	
amber-winged spreadwing	6	s
hagen's bluet	6	s
swamp spreadwing	6	s
beaver/common baskettail	6	
ebony jewelwing	6	
aurora damselfly	4	s
calico pennant	4	s
double striped bluet	3	
shadow darner	3	
marsh bluet	2	s
lancet clubtail	2	
atlantic bluet	1	s
big bluet	1	
chalk-fronted coporal	1	s
eastern red damselfly	1	
tourquoise bluet	1	s
harelequin darner	1	
lancet darner	1	
rackettailed emerald?	1	
southern spreadwing	1	
stream cruiser	1	
unicorn clubtail	1	
vesper bluet	1	

Table 7. (Right) A list of the occurrence of dragonfly species in our ponds. Species marked with an "S" were included in our Specialist Odonates category.

Fig. 74. A Spreadwing preying on one member of a mated pair of Phantom Craneflies. Both species occurred regularly around our grassier, shrubbier ponds. Dragonflies and damselflies are insect predators and may help control mosquito and blackfly populations.

Fig. 75. A Dragonfly (possibly a Meadowhawk) excloses. Dragonflies and damselflies lay their eggs in the water and these develop into aquatic larvae which eventually crawl up into the air and "exclose" to reveal the winged adult.

areas. The former group tends to include the more common species on our list (e.g., the forktails, pondhawk, dasher and skimmers), while the latter group tends to include, as one would expect, some of the rarer species.

Based on a review of habitat requirements, we included the following species in our "specialist" group: Sweetflag Spreadwing, Swamp Spreadwing, Atlantic Bluet, Azure Bluet, Hagen's Bluet, Calico Pennant, and Halloween Pennant. The details are surely debatable, but we will call this group the "Specialists". We call the

Fig. 76. A damselfly, probably a Skimming Bluet, rests on duckweed. Damselflies have dantier bodies than dragonflies and close their wings over their backs when landed.

Fig. 77. A Halloween Pennant. Gaudy as some butterflies, we considered the pennants to be some of our specialized odonates. This dragonfly is holding its wings open in the typical perching stance of dragonflies. We caught (and then released) a couple of these to inspect when we were still learning, however, as one can easily imagine, they could be readily identified on the wing.

remainder "Generalists". Below, we present two sets of analyses – one for our so-called specialist species and one for the generalist group. It seems logical to do both. On the one hand, one would like to simply know how conducive a given habitat is to your run-of-the-mill odonates that might use it; on the other hand, by highlighting what might be somewhat more sensitive species, we might better understand how suitable our ponds were for the more discerning species.[24]

Please note, specialist and generalist are relative terms – a species that might be a habitat generalist might be a specialist in other regards (e.g., courtship); furthermore, we were particularly interested in the group that tended to favor a restricted set of *pond* habitats. The Big Bluet, for example, is thought to be something of a slow river "specialist", that species' occurrence in one of our ponds near the Hudson probably reflected the location of the pond rather than the habitat it provided; we did not classify Big Bluet as a specialist.

Here's the regression report that looks at the factors correlated with the abundance of our specialists:

Dependent Variable: **Specialist Dragonflies & Damselflies**
% of Variation Explained by Model: **15%**
Number of Ponds in Analyses: **84**

Significant Variable	Standardized Coefficient	"Significance" of Effect
Presence of Fish	**-0.215**	**0.039**
% Pasture within 100'	**0.306**	**0.004**

This is not a terribly strong set of relationships, only about 15% of the variation is explained. The presence of fish was associated with reduced numbers of specialist dragonflies, while their abundance increased with the amount of pasture in the proximity. The relevance of fish has been noted by others; fish can be direct predators on larvae and, to some degree, on adults. The specialists were, as we defined them, those species which were reported to be restricted to vernal (seasonal) ponds and marshy areas. One of the main ecological consequences of a vernal pool is the absence of fish, and vernal pool organisms tend not to be adapted to fish.

The relevance of grazed margins or of pasture (Fig. 78) was less intuitive for us than the role of fish. In the case of the dragonflies (and unlike the case of butterflies which we shall explore next), we believe that this correlation may have been primarily due to a relationship between the abundance of these odonates and the vegetation of the pond margins (Fig. 79).Yet, read the following description of good pond margin habitat, taken from a Scottish document on habitat management for dragonflies:

> *An ideal situation consists of a mixture of both long and short grassland and even bare ground near the water's edge, with scrub and woodland nearby. This should provide areas for hunting, roosting and basking away from the intense competition that can exist at the breeding site itself.* [25]

Although the authors don't say so, this is quite a good description of the margins of a pond in extensively grazed pastureland. Most specialist dragonflies apparently shun heavily shaded, densely-wooded pond banks and yet are not at home along the close-clipped, tidy margins of lawn ponds. Ponds in pasture are apparently a happy medium. Given that fish were more common in residential than agricultural ponds and few people graze their lawns, specialist odonates were more common around agricultural rather than residential ponds (Fig. 80).[26]

The only factors "significantly" correlated with the abundance of generalist dragonflies and damselflies were those related to pH. Ponds on more alkaline soils had more odonates (Fig. 81). We have seen a similar importance of pH amongst plants.

> *We found 47 species of dragonflies and damselflies during our study. The total abundance of specialist odonates (i.e., those that are reported to prefer marshy areas or vernal pools) was reduced in ponds with fish and higher in ponds with grazed banks, possibly because grazing creates better habitat structure.*

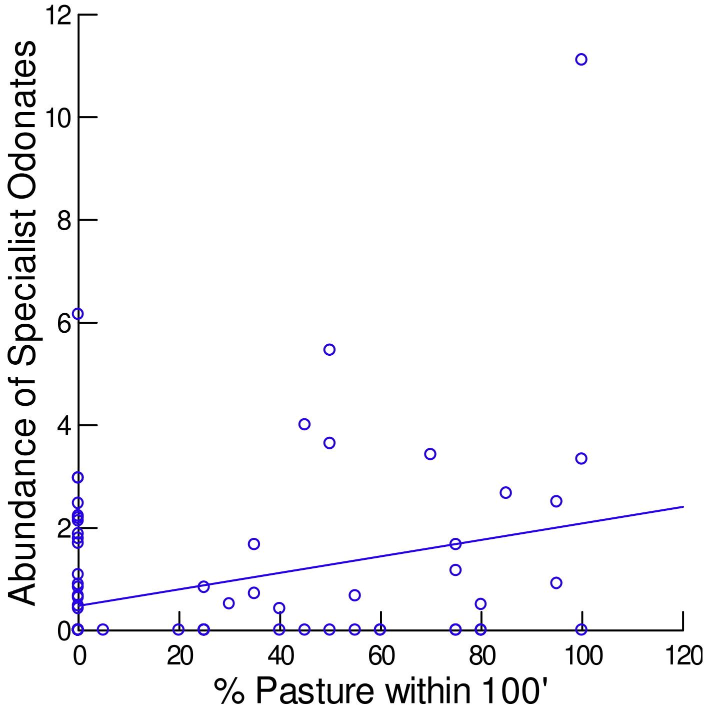

Fig. 78. The abundance of specialist dragonflies and damselflies vs. amount of nearby pasture. These odonates appeared to be most common at ponds in pastured landscapes. A similar pattern existed with wetland butterflies, although perhaps for a different underlying reason.

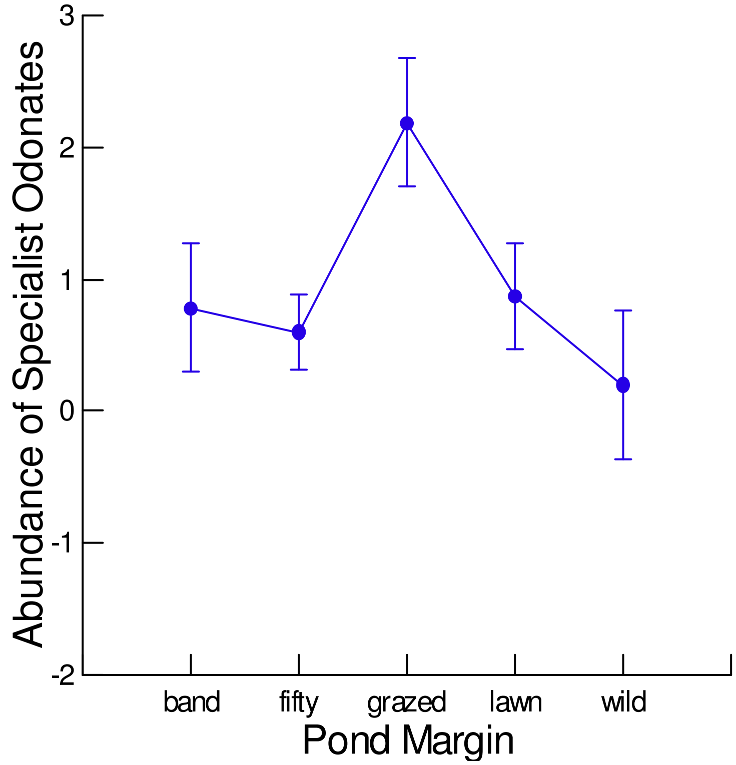

Fig. 79. The abundance of specialist odonates at ponds with a variety of bank characteristics. "band" = a narrow band of uncut vegetation around banks midst lawn or intensive grazing; "fifty" = pond partially bounded by "wild" margin and partially by lawn or pasture; "grazed" = pond bounded mostly by extensive grazing; "lawn" = pond bounded mostly by lawn; "wild" = pond with unmanaged banks.

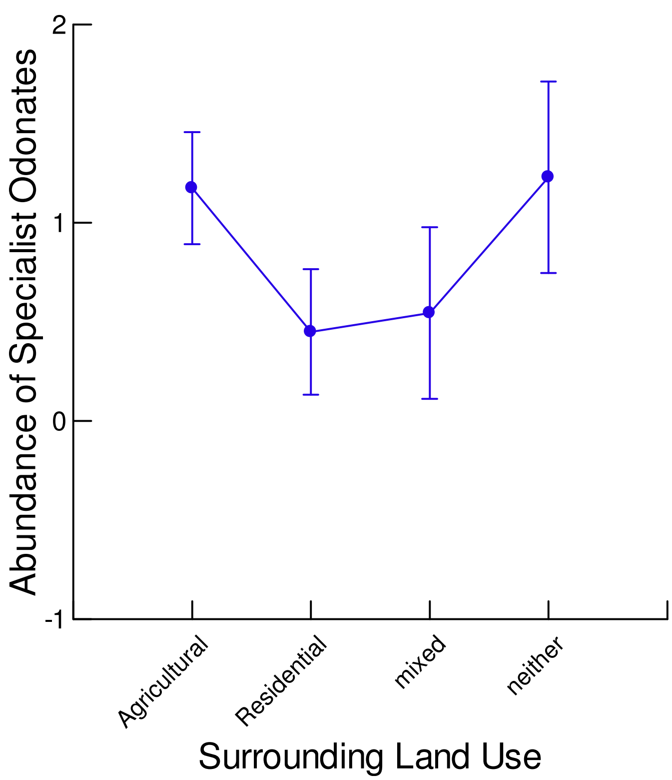

Fig. 80. The abundance of Specialist Dragonflies and Damselflies at ponds in different land use contexts. These insects tended to be more common at agricultural than residential ponds.

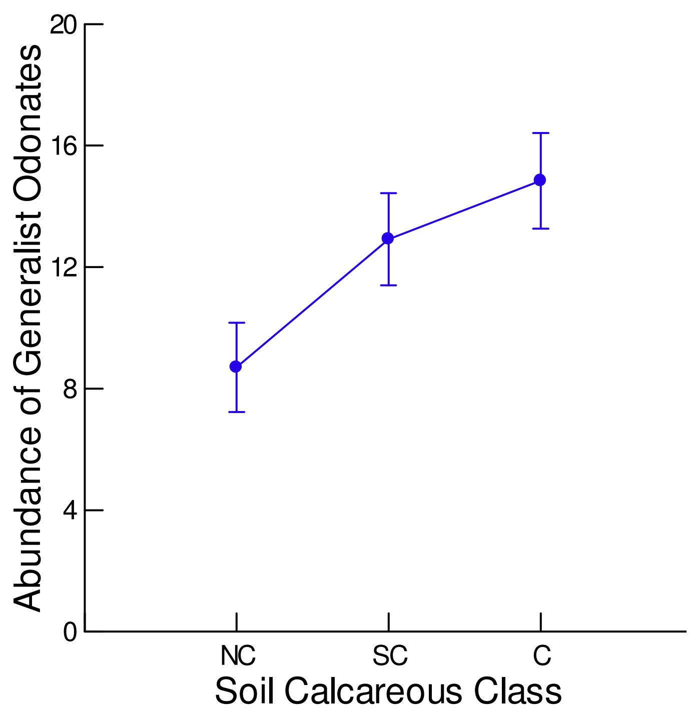

Fig. 81. The abundance of generalist dragonflies and damselflies vs. calcareousness of soils. In our sample, ponds located on more basic, alkaline soils tended to have more dragonflies.

BUTTERFLIES – A FEW WHO HIDE IN A WETLAND NURSERY

Butterflies are not aquatic, yet the caterpillars of certain species favor wetland plants that are sometimes found around ponds. For example, the caterpillars of Baltimore Checkerspot (Fig. 86)feed upon Turtlehead (Fig. 52), while those of the Mulberry Wing (Fig. 85) and Black Dash favor sedges. The Bronze Copper (Fig. 82) also seems to be confined to wetlands, although its food plants (various species of *Rumex* or Dock) are not. Butterflies can thus serve as yet another biological perspective from which to evaluate the quality of a wetland.

We did visual surveys, roaming the margins of the ponds, and doing species-specific counts of all butterflies seen. As with dragonflies, the length of the survey was noted and counts were standardized based on the duration of the survey. We chose this approach over fixed length surveys because our primary goal was to list all butterflies flying at the given pond during the survey visit. Because ponds differed markedly in size, structure, and butterfly abundance, we used varied survey lengths. Butterflies were identified on the wing. When necessary, a digital camera was used to capture images for subsequent identification.

Different butterfly species fly at different times of year. Often this has to do with the growth timing of their caterpillar's food plants. Although we tallied all the butterflies that we saw during each survey, our standardized counts only included those which reportedly fly for all or most of our June to early September survey period.[17]

Fig. 82. A Bronze Copper rests on Blue Flag Iris. These showy little wetland butterflies were relatively uncommon. During the summer, we found them at only three of our ponds.

Occurrence of Butterflies
Columbia County Ponds
(92 ponds visited)

Species	% of Ponds Where Found	
cabbage white	76	
pearl crescent	61	
sulphur	51	
monarch	50	
least skipper	42	(W)
common wood nymph	30	
eastern-tailed blue	26	
orange sulphur	21	
black swallowtail	20	
great spangled fritillary	20	
baltimore checkerspot	15	W
european skipper	14	
tiger swallowtail	13	
common ringlet	12	
viceroy	11	
peck's skipper	8	
eyed brown	7	W
meadow fritillary	7	
silver-spotted skipper	7	
american copper	5	
mullberry wing	5	W
northern broken dash	4	
black dash	3	W
bronze copper	3	W
comma	3	
broad-winged skipper	2	W
little wood satyr	2	
red admiral	2	
spicebush swallowtail	2	
aphrodite fritillary	1	
banded hairstreak	1	
common buckeye	1	
crossline skipper	1	
little glassy wing	1	
mourning cloak	1	
red-spotted purple	1	
striped hairstreaks	1	
tawny-edged skipper	1	
wild indigo	1	

Table 8. A list of the butterflies found around the ponds we studied. Species accompanied by a "w" are ones that we included in our group of wetland butterflies. The Least Skipper, while not confined to wetlands, was distinctly more common in such habitat.

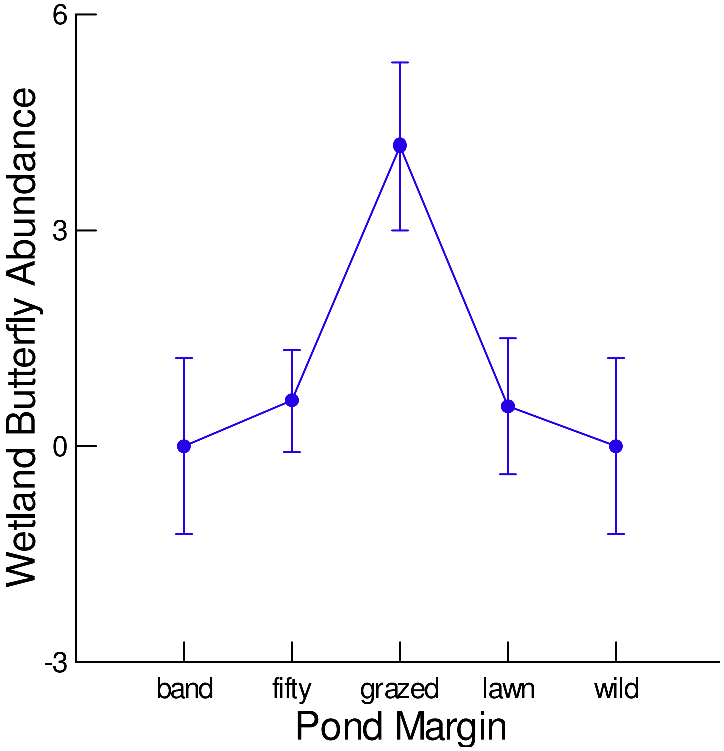

Fig. 83. The average abundance of wetland butterflies in ponds with different classes of margins. See Fig. 79 for an explanation of the margin types. Wetland butterflies seemed to be most common at ponds with grazed margins.

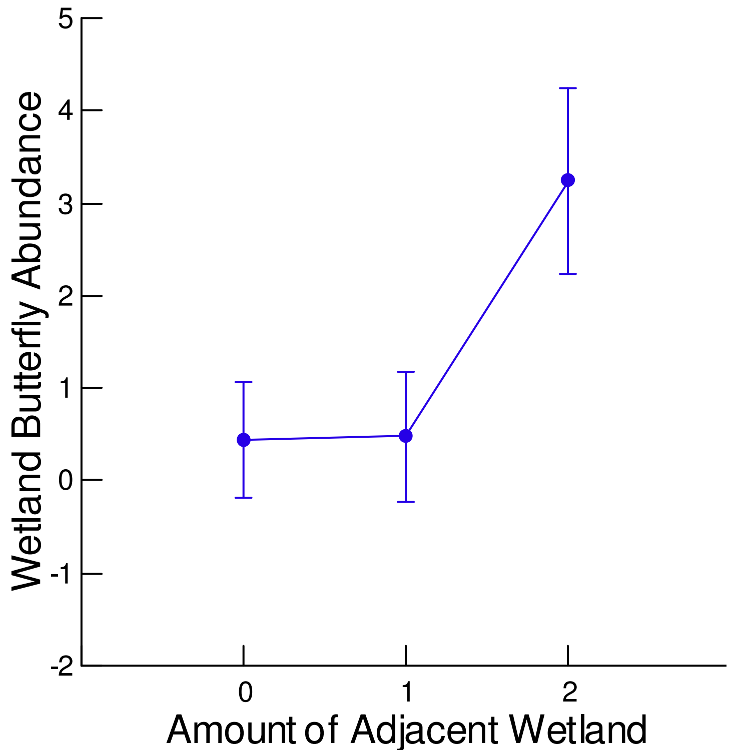

Fig. 84. Wetland butterfly abundance around ponds in comparison with amount of adjacent wetland. Unlike the specialized dragonflies, wetland butterflies seemed to be responding to amount of adjacent wetland.

Fig. 85. A Mulberry Wing nectars at Red Clover. While the adults of many butterflies are relatively undiscriminating in terms of the flowers that they nectar on, the caterpillars tend to be more picky. The caterpillar of this small wetland skipper feeds on sedges.

We tallied 39 species of butterflies around our ponds (Table 8). Most of these were open-area generalists, butterflies whose habitat preferences and food habits as caterpillars are general enough that they have widespread occurrence. However, six or seven of these species were more particular. We classified Baltimore Checkerspot, the Black Dash, Bronze Copper, Broad-winged Skipper, the Eyed Brown and the Mulberry Wing, as wetland butterflies, although the last was not included in our initial analysis because of its relatively short flight season.

As with the specialist dragonflies, wetland butterflies were most abundant at ponds with grazed margins (Fig. 83). However, rather than reflect a direct link to habitat structure, we believe this correlation was due to the fact that pastured ponds tended to have more adjacent wetland habitat, and the butterflies were probably responding to the increased abundance of their required favored haunts (Fig. 84). It would be interesting to explore the occurrence of these butterflies in more depth, but wetland butterflies were only recorded at *six ponds*. Such a small number of occurrences limits the extent to which we can "chew" these data, and means that the few sites where such butterflies were present hold heavy sway over any statistical analysis. (Because of this small sample size, we're not including any regression table for butterflies). By including one species of wetland butterfly which flew only for part of the year (the Mulberry Wing), and another which was more loosely tied to wetlands (Least Skipper), we could increase our sample size. The result? Variation increased but the pattern remained the same – more surrounding wetland, more wetland butterflies.

Most of the butterflies we saw were generalists. There is no particular reason to suppose that they have any particular relation with ponds, and we will not explore their occurrence in any detail. Suffice it to say that they appeared to show surprising correlations with pond depth and sediment chemistry. We believe the former relation derives from pond depth's previously-noted relation to age and purpose of a pond, and the concomitant broader landscape aspects associated with these differences. The relation to pond sediment chemistry was intriguing and, we assume, may reflect relationships to broader regional patterns of pollution deposition. It is not difficult to believe that the abundance of butterflies might be influenced by, among other things, excessive lead and copper levels in the soils of their food plants. In that case, the pond sediments are but flags for what is occurring in the surrounding land and, likely, affecting the butterflies directly. Intriguingly, other European biologists have reported just such a link between contamination and butterfly declines.[27]

Fig. 86. Baltimore Checkerspot. The young caterpillars of this wetland butterfly sometimes feed on Turtlehead (Fig. 52), although the species apparently has other foods and main not be as tied to wetlands as some other butterflies.

We found 39 species of butterflies around our ponds. We classified a small subset of these as "wetland butterflies" and explored their occurrence in more detail. Wetland butterflies appeared to be associated with ample wet meadow adjacent to the ponds; wet meadow, in turn, was associated with grazed areas. Generalist butterflies showed a strong relationship to sediment chemistry.

THE WHOLE KIT 'N KABOODLE

So far, we have looked at ponds through the "eyes" of four different sets of organisms: plants, butterflies, dragonflies, and amphibians. Given the different biologies of these species, it seems reasonable to assume that they provide somewhat differing perspectives on the ponds. Yet, at the same time, given that they are all living organisms, it would also seem reasonable to assume that they may respond similarly to certain aspects of their landscape. True, people from different cultures (and even within cultures) will have different ideas of what makes a 'good' home; however, they'd probably all agree that warmth, dryness, safety, and relative quietness are amongst the desirable traits. Do our organisms show similar consensus around any landscape factors? Can we make any broad statements about what favors a diverse pond?

It appears we can. To address this question, we standardized each diversity value. For example, we calculated the average number of butterfly species around our ponds, divided the observed number at any particular pond by that value, and then expressed the difference in terms of a proportion of the total observed variation (technically, we divided by the standard deviation). This let us express plant diversity (where a total of up to 84 species were possible at any one pond) and frog diversity (where a maximum of eight species were observed at one pond) on the same scale, and likewise across the remaining groups. A somewhat analogous approach is taken in schools, where a comparable set of grades is applied across subjects even though each subject area may have a different "grade curve" and a different number of tests.

First, we asked simply, how intercorrelated are our four measures of diversity? Although amphibian diversity was uncorrelated with any of the other three measures, *the plant, butterfly and dragonfly diversity indices were all significantly intercorrelated* (e.g., Fig. 87). This means, for example, that knowing the number of butterflies at a given pond can help you predict the number of dragonflies it will have, and vice-versa. This may occur because these organisms are responding in broadly similar ways to their environments, e.g., what's good for a flower is good for a butterfly. Or, it may mean that healthy habitats of one sort tended to co-occur with healthy habitats of another. For example, people who plant butterfly gardens may also tend to treat their ponds more benignly or farmers who left ample room for wildflowers, also tended to leave ponds in good order.

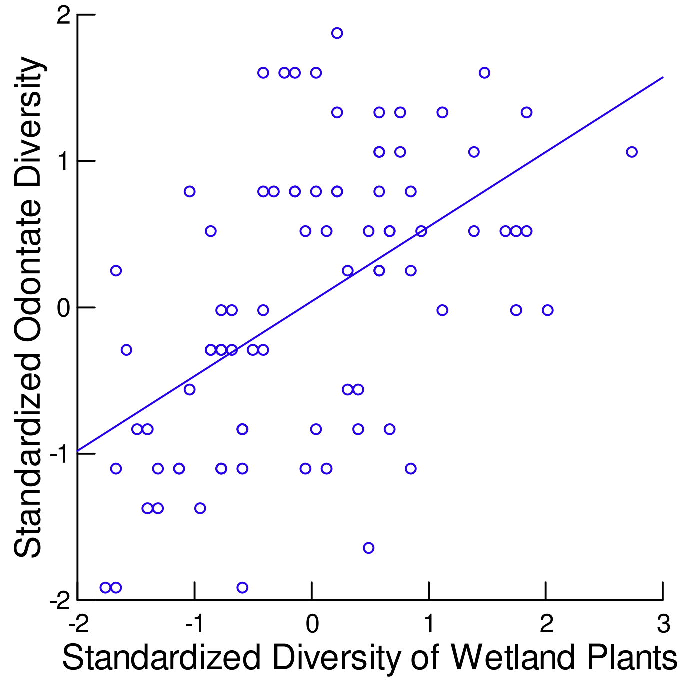

Fig. 87. The diversity of wetland plants vs. that of dragonflies and damselflies. This is an example of a relatively strong correlation between the diversity of two distinct sets of organisms.

Thinking about our data in this way led us to conclude these analyses with one final probing for correlations between diversity and landscape/pond characteristics. (And you thought you had seen the last of those bothersome regression tables!) We calculated the average diversity of a given pond across our four, standardized diversity measures. When data were missing for a given taxonomic group, the average was calculated based on the reduced set of numbers. This value, which we'll humbly call Grand Diversity, can be thought of as a first estimate of the overall, diversity-supporting value of each pond. Was Grand Diversity correlated with any of the environmental factors we measured?
Here's the relatively simple model:

Dependent Variable: **Average Relative Diversity across Taxa (i.e., "Grand Diversity")**
% of Variation Explained by Model: **12%**
Number of Ponds in Analyses: **90**

Significant Variable	Standardized Coefficient	"Significance" of Effect
pH	**0.277**	**0.007**
Non-Agricultural Development	**-0.257**	**0.013**

Not surprisingly, two of the factors which we have seen before, pH (Fig. 88) and our non-agricultural development component (Fig. 89), were significantly related to Grand Diversity. Increased pH was correlated with increased diversity; increased non-agricultural development was associated with diminished diversity. While these correlations were highly significant, and readily understandable, they explained only about 10% of the total variation in Grand Diversity. As Figs. 88 and 89 illustrate, much variation is left to be explained. We will summarize these results another way by returning to the land use categories that we used earlier and asking how Grand Diversity compared across ponds in different land use contexts (Fig. 90). As those who have

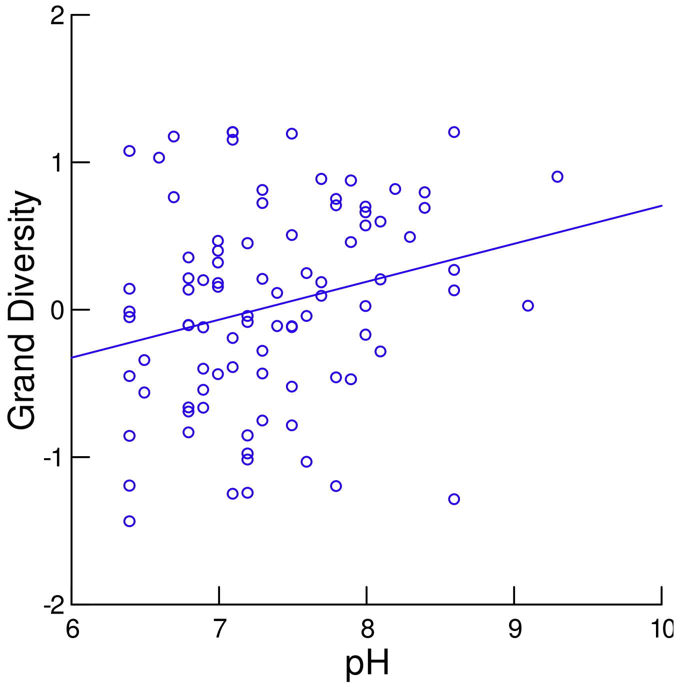

Fig. 88. The relationship between pH and Grand Diversity. Diversity across plants and animals tended to increase with increasing pH, although much variation remained to be explained.

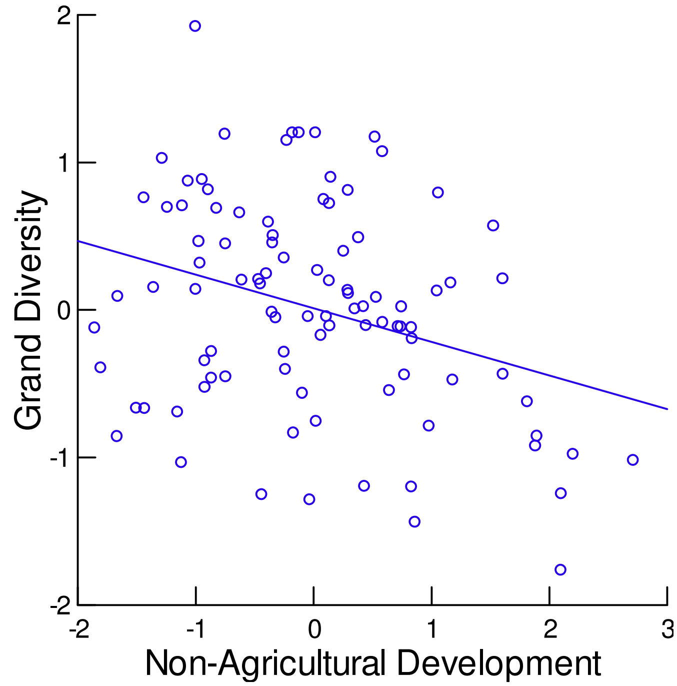

Fig. 89. The relationship between non-agricultural development and Grand Diversity. Diversity across plants and animals tended to decrease as non-agricultural development increased.

followed our results so far might suspect, Grand Diversity was highest around relatively wild (yet open) ponds, followed by agricultural ponds, with residential and mixed use ponds falling noticeably lower.

This is fitting closure for our analyses. Two factors, one associated largely with the natural landscape (pH) and the other primarily a human construct (non-agricultural development), may be influencing the life of our ponds. The potential for agricultural ponds to support a relatively high diversity of amphibians has been noted by biologists working elsewhere in New York and in the Midwest. Others have commented on the diversity of some agricultural landscapes for butterflies and grassland plants. We believe that such results are important to highlight, as we continue to lose agriculture land in the Northeast, and given the public perception that agricultural and nature conservation are not generally compatible. That said, we must also caution that, while both conventional and organic farms were included in our sample, they are hardly representative of all agriculture in the United States or even in Columbia County. These results indicate the *realizable potential* for agriculture and nature conservation to co-exist, they do not indicate that such a synergy can be taken for granted. Finally our results caution us to look at our own backyards—neat and trim backyard ponds, beautiful as they might appear, do not necessarily benefit the

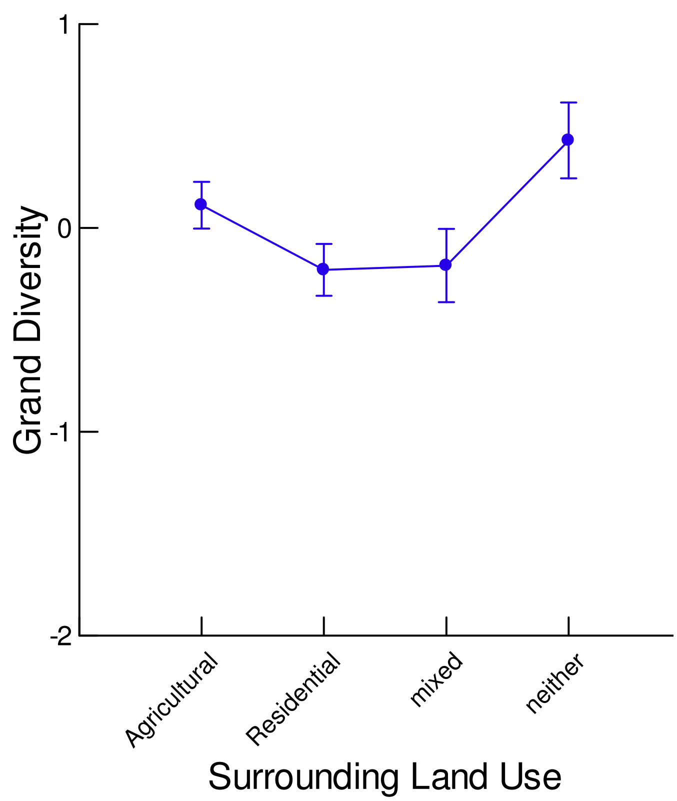

Fig. 90. Grand Diversity across ponds surrounded by different land uses. Diversity of plants and animals was highest in ponds located in relatively unused (but open) areas, followed by those in agricultural areas.

Fig. 91. A natural vernal pool. The rising and falling water level of such ponds creates a vegetation structure somewhat similar to that of grazed ponds. Importantly, the seasonal drying out of vernal pools excludes fish and larger amphibian predators such as Bull Frogs. The stocking of ponds with fish generally reduces their native animal diversity.

Fig. 92. A dug pond bordered by a beaver-created wetland. Beaver ponds have a life cycle from open pond through beaver meadow to more or less solid land. When beaver are allowed to follow their whims, the lowland landscape becomes a dynamic patchwork at various stages of flooding and regrowth.

organisms that live around them. If we want to encourage native diversity around our ponds, we need to do so consciously.[28]

The next section is an ecological segue to our final thoughts on management. If you are thinking about constructing a pond, we first ask you to think about where you're putting it, then we ask you to think about how you manage it.

The diversity of pond plants, butterflies, and dragonflies was highly intercorrelated. Amphibian diversity appeared to follow somewhat distinct patterns. We calculated a single measure of diversity across plants, dragonflies, butterflies and amphibians and gave it the modest name "Grand Diversity". Grand Diversity increased as pH increased (i.e., in more basic or alkaline habitats) and as non-agricultural development decreased. This reflects patterns that we saw in our analyses of the individual groups, and illustrates the combined hand of nature and humans in producing the patterns we see

Conclusions

THINKING ABOUT BEFORE – WHAT DO PONDS REPLACE?

A central question concerning the ecological role of the newly constructed ponds in our landscape is the following: *what are they replacing?* Are these ponds that are appearing de novo on dry upland? Are they the result of digging out wetlands? Are they empoundments of streams? In other words, are our newly-constructed ponds adding aquatic habitat where there was none or are they converting one kind of aquatic habitat to another? For the ecological bottom line, this is an important consideration: are we building aquatic habitat or, perhaps, degrading it?

Historical data on land cover is difficult to obtain. Historical aerial photographs can, for example, give you a good idea of whether or not open water was present sixty years ago, but judging wetland status can be more difficult. We made a preliminary assessment of what habitats dug ponds replace based upon a pond's position in the landscape, its surrounding vegetation, and some historical information. We classified all the recent ponds (i.e., ones not present in the 1940s) into four classes: those that we believe probably did replace wetland, those that are empoundments on streams or creeks, those that we are fairly sure were dug in upland areas, and those for which we have no good idea. While these numbers are hardly precise (Table 9), they can

Construction Context	% of 84 ponds
Replaced Wetlands	23
Empounded Streams	20
Created in Upland	36
Unknown	21

Table 9. Our first approximation concerning the ecological history of our 84 dug ponds. Perhaps 1/4 to 1/2 of the ponds replaced pre-existing wetlands or stream corridors.

help us estimate the possible scale of wetland degradation or creation.

Based on these calculations, we estimate that from around ¼ to a little less than ½ of the constructed ponds replaced wetland, meaning that pond construction may regularly be concomitant with wetland loss. The consequences of stream empoundment may be ecologically mixed – for example, a beaver pond (or a constructed analogue) can create valuable wet meadow where there was previously a narrow creek. On the other hand, the creation of a well-kempt ornamental pond in an area where a fairly broad and marshy stream previously flowed could signify a decrease in ecologically-valuable wetland habitat. Our numbers are very rough and our analysis incomplete, however we believe that this is an important topic that should be considered as one assess the consequences of our pond building habits.

A FEW BRIEF THOUGHTS ON POND MANAGEMENT - BEAUTY'S IN THE EYE OF THE BEHOLDER

Ponds, as many have said, are micro-cosmos or tiny worlds where many of the ecological processes occurring on the less-bounded landscape around them are played out in miniature and in relative isolation. While this may be a useful perspective, ponds are also in some ways focal points for all that is happening around them, semi-discrete points where the net effects of contamination and land use in the surroundings are expressed succinctly. A pond is a cosmos in which the shower of materials from the outside world is intense. And we have control over at least part of that deluge.

A variety of books, articles and websites focus on pond and lake management. We especially recommend Winfield Fairchild's Pond Management web site. The link to this and several other resources are listed in the reference section, It is not our goal to review those here. We do want to conclude by tying together some of our results with pond management.[29]

First, a pond owner has to decide why they want a pond. Do they want a cattle watering spot? A fishing hole? A swim pond? A more natural wetland (e.g., Figs. 91 and 92)? Some uses are inherently more compatible than others with nature conservation. Our results have, for example, highlighted an apparent tendency for pasture ponds (Fig. 93) to support relatively high biological diversity. Rather than there being a direct link between pond diversity and cattle, the relationship may be more indirect, i.e., the ponds that support cattle and those that favor native species may have some shared traits. We put together Table 9 to facilitate the comparison of pond traits amongst ponds of different uses.

Fig. 93. A pasture pond. Notice that while the grass is cropped, the margins of the pond are relatively irregular, there is emergent vegetations, shoreline vegetation of varying structure and a wetland margin.

The characteristics listed across the top of the table are ones that our results and or the literature have suggested are important for the

		ASSOCIATED CHARACTERISTIC					
		Fish	Mowed Margins Preferred	Marshy Shallows and Wetland Surroundings	Fertilization on Surrounding Land and/or Septic Tank Leakage	Woods Nearby	"greenness allowed"
POND TYPE	Irrigation Pond or Watering Hole	+/-	-	+	+/-	+/-	+
	Swim/Ornamental Pond	+/-	+	-	+/-	+/-	-
	Natural Wetland	+/-	-	+	-	+	+
	Fire Pond	+/-	-	+	-	+	+/-
	Fishing Pond	+	+/-	+	-	+	+/-

Table 9. A characterization of ponds based upon their uses and some associated characteristics that are relevant to nature conservation. No doubt this is a simplified classification and exceptions can be found in all categories. "+" means that the given pond type tends to have the particular characteristic; "-" means it doesn't; "+/-" means it can go either way.

native species of ponds: the presence of fish appeared to reduce amphibian diversity when there was little shelter, specialist dragonflies seemed to prefer unmowed pond margins; pond nutrient state was related to amphibian diversity (in our results, the effects were positive, however the literature has documented the negative consequences of high nutrient levels); nearby woods appeared to benefit vernal pool amphibians; and, while we did not tally algal control per se, the more highly managed ponds, some of which we know to have been treated to reduce algae, were not our most diverse.

Our characterization of each type of pond surely suffers from stereotyping, but to a certain degree that is our point. An ornamental pond need not have mowed margins, cleaned banks, be located in the middle of a golf green and be treated for algae. Yet, it is important to realize that what might seem aesthetically appealing to us (e.g., Figs 94 and 95) may not necessarily be the most suitable for supporting native plants and animals. Owning a natural pond requires, perhaps, more work on oneself than it does on one's pond. Semi-natural ponds aren't always easy to appreciate. They can be scraggly, noisy, perhaps buggy, places (e.g. Fig. 96). But they can also be intimately beautiful in ways more gaudy water bodies cannot be.

As Table 9 suggests, management is not all or nothing. Perhaps one really wants a fishing pond, for example. Ensuring that it has margins that are largely, but not necessarily entirely, 'in the rough' and allowing wet meadow to develop around a seeping outflow is still likely to help diversity. Similarly, a narrow mowed strip that lets you peruse your pond without fighting ticks or raspberries, might be integrated into a lighter-

Fig. 94. This is a pretty, well-kept pond, however the close cut lawn which surrounds it and the channelized waterways entering and leaving it are not ideal for most wetland life.

Fig. 95. Ponds with close-mown margins and little emergent vegetation seemed to be less biodiverse in our sample. Happily, although not visible in this picture, cattails had been left along one margin of this pond and a vigorous flower garden provided ample nectar for butterflies.

handed bank management (Fig. 97). Locating your farm pond near the woods and not stocking it with fish can have positive environmental effects even if cattle trampling and manure might bring some negatives.

Because so much of what determines how appealing a pond looks to us is fashion, we have found it truly helpful to look at the pictures in publications such as the Minnesota DNR's *Lakescaping for Water and Wildlife*. Very much a gardening book of sorts, this publication does a nice job of mixing the human-created with the natural, and helps one form a new vision of what the managed, yet ecologically-valuable surroundings of a lake (or pond) can look like.[30]

Finally, and importantly, we believe that understanding pond management depends, in part, on understanding greater context. For example, while a leaking septic tank may or may not turn your pond into pea stew, the nutrients seeping from thousands of such tanks may have major ecological consequences in estuaries hundreds of miles away. Furthermore, we need to try to envision the landscape to which most of our native species are adapted, and then ask how that compares to our current surroundings. We have done that implicitly in this report. For example, the natural ideal that we included in Table 9 and elsewhere in this report is a pond more closely resembling a vernal pool or beaver pond than an isolated but permanent woodland pond. The last does exist and can be important for biodiversity, however we are living in a landscape that is currently perhaps more tolerant of wooded ponds than it is of beaver meadows or vernal pools. Our management thoughts need to include consideration of the discrepancy between the landscape that our resident species "got to know" evolutionarily and the modern one. If, for example, you are a non-farmer who has purchased recently grazed land that contains a large wet meadow, then you should consider how to maintain the openness of that meadow. A laissez-faire approach will likely result in thicket and eventual forest. Originally, such openness was probably maintained in the landscape by the fluctuating waters created by the activities of beaver and natural flooding; two factors that have been more heavily controlled during recent history. Conversely, a small shallow pond nearly surrounded by woods, might best be allowed to develop towards (or to remain) a vernal pool rather than being dug out. Vernal pools are disappearing from our landscape because they seem like little more than large puddles. It is because we have so drastically altered the structure and dynamics of our landscape that we must be so conscious in our management.

Rather than being a direct management tool, we hope these words are hints and inspiration for pond connoisseurs. Once you're inspired, much can be learned from observation and reading. By realizing what your pond does or could harbour, we hope that you grow to appreciate it for what it is: haven for aquatic

Fig. 96. Another pond with grazed margins indicating what may make such a site especially suitable for wetland dragonflies and butterflies. Note the varied heights of the emergent and shoreline vegetation, and the presence of some shrubs.

Fig. 97. The owner of this pond has struck a balance between access and ecology—a narrow mowed strip permits ease of access but the shoreline and much of the adjacent field is cut much less regularly resulting in ample natural structure.

species, stop-over for the semi-aquatic, microcosm and part of our macrocosm. Go out. Listen. Sniff. Look. Wade. Meet your aquatic neighbors.

We end our report by considering the application of our results to pond construction and management. Perhaps a key first step in managing a human-made pond is considering where to build the pond in the first place. We estimated that 1/4 to 1/2 of the dug ponds in our study replaced natural wetlands or stream courses. As such, they may have resulted in a decline in the ecological value of the extant aquatic habitat. In considering management, we outline the interaction of pond purpose and nature conservation and, we hope, stimulate those interested in actively managing their ponds to consider how to incorporate ecology into not only the techniques but also the philosophy of their management.

Acknowledgments

This work would not have been possible without the efforts, patience and hospitality of many people. The numerous land owners who tolerated our slogging about at odd hours (some frog-calling surveys lasted until well-nigh midnight) provided crucial hospitality without which this study could have never started. Our fieldwork involved the efforts of many hands (and feet, and eyes). These included (in alphabetical order): Ric Fry, Michelle Garvie, Martin Holdrege, Sara O'Martin, Sarah Noel Ross, Vivian Schoung, Otter Vispo, and the various landowners and their families who showed us about or even joined us in the field. Numerous fellow scientists shared their expertise as we explored topics with which we had little familiarity. Key amongst these were (again in alphabetical order): Bob Daniels, Larry Federman, Stuart Findlay, David Fisher, Barre Hellquist, Keith Pilgrim, Gretchen Stevens and Bruce Young & the botanists of the Natural Heritage Program. Aside from important support from individual donors, the following organizations provided important funds: NYS DEC's Hudson River Estuary Fund, the David Rockefeller Fund, the Berkshire-Taconic Foundation, and the Kaplan Fund. The Farmscape Ecology Program is part of the Hawthorne Valley Association, and receives important aid and abetment in their activities from the Association and its components. Cornell University's Dept. of Natural Resources and the University of Wisconsin's Institute for Ecosystem Studies provided crucial access to academic resources. Mountain Buddies of Hudson leant us a kayak at a crucial stage of our pond explorations. Our sincere thanks to all the individuals and organizations who helped make this work possible.

Notes

This is still is a work in progress—there are many more references that should be read and included. We hope to better our inclusion of other works as time goes on.

1. The report summarizing recent wetland trends is T.E. Dahl. 2006. *Status and Trends of Wetlands in the Conterminous United States 1998 – 2004* published by USGS. It is available on-line at wetlandsfws.er.usgs.gov/ status_trends/index.html. His publication along with G.J. Allord, entitled *The History of Wetlands in the Conterminous United State* provides a nice summary of wetland history. It is U.S. Geological Survey Water Supply Paper 2425. It is on-line at water.usgs.gov/nwsum/WSP2425 /history.html.

2. Our own report, written by us (C. Vispo and C. Knab-Vispo) is entitled *The Flora & Fauna of Some Columbia County Farms: Their Diversity, History and Management.* It was printed by the Farmscape Ecology Program in 2006 and a digital copy is available from us upon request. Based on work in southeast Minnesota, Melinda Knutson, along with W.B. Richardson, D.M. Reineke, B.R. Gray, J.R. Parmelee, and S.E. Weick, published the article *Agricultural Ponds Support Amphibian Populations* in 2004 in volume 14, pages 669-684 of the journal 'Ecological Applications'. In the Northeast, J.P. Gibbs, K.K. Whiteleather, and F.W. Schueler discussed agriculture and amphibians in their 2005 paper *Changes in*

Frog and Toad Populations over 30 Years in New York State. It was published in volume 15 of ‘Ecological Applications’, pages 1148–1157.

3. G. Winfield Fairchild’s publication is *Ecologically Based Small Pond Management*, published in 2004 by the Chester County (PA) Water Resources Authority. It can be downloaded at darwin.wcupa.edu/ponds/summary.html.

4. The use of plants to help remove toxins for sediments and soils is called “phytoremediation”, one web site that lists introductory materials is www.mobot.org/jwcross/phytoremediation/.

5. A summary of acid rain’s effects on the Adirondacks can be found in *Acid Rain and the Adirondacks: A Research Summary* by J. Jenkins, K. Roy, C. Driscoll and C. Buerkett, published by the Adirondack Lakes Survey Corporation, Ray Brook, NY, in 2005. It is available on-line at www.adirondacklakessurvey.org/.

6. A key resource of understanding the biodiversity of our area is Hudsonia’s *Biodiversity Assessment Manual for the Hudson River Estuary Corridor* by Erik Kiviat and Gretchen Stevens published in 2001 by NYS DEC.

7. For a thorough consideration of our county’s tumultuous geological history, consult *The Rise and Fall of the Taconic Mountains: A Geological History of Eastern New York* written by D.W. Fisher and S.L. Nightingale and published in 2006 by Blackdome Press.

8. OK, so this is a blatant plug for our own work, but heck it’s nice to tie in different parts of one’s life works. A discussion of the relation between water nutrients and neotropical fish abundance/diversity can be found in chapter 6 of *Plants and Vertebrates of the Caura’s Riparian Corridor: Their Biology, Use and Conservation,* edited by us and published in 2003 as ‘Scientia Guaianae’ volume 12. If you’re really interested, let us know and we’ll send you a copy of the chapter.

9. The 2003 Wisconsin DNR guidance document referred to is their report QT-732 2003, entitled *Consensus-based Sediment Quality Guidelines: Recommendations for Use and Application*. It was assembled by the Contaminated Sediment Standing Team and is available on-line at www.dnr.state.wi.us/org/aw/rr/technical/cbsqg_interim_final.pdf.

10. See, for example, E. Steinnes and A.J. Friedland’s *Metal contamination of natural surface soils from long-range atmospheric transport: Existing and missing knowledge.* It was published in 2006, volume 14, pages 169-186 of ‘Environmental Review’.

11. A nice short summary of eutrophication and other aspects of lake ecology is available at waterontheweb.org/under/lakeecology/index.html

12. While all the ponds that we studied were permanent ponds and hence not true vernal pools, the ecologies of some of our ponds had vernal pool aspects. To understand more about these pools, we recommend E.A. Colburn’s 2004 *Vernal Pools: Natural History and Conservation* published by the McDonald & Woodward Publishing Company of Blacksburg Virginia. Elizabeth Colburn is based at the Harvard Forest and much of the work has regional relevance.

13. A nice intro to pond gunk and other interesting “aquatic phenomena” is the *Field Guide to Aquatic Phenomena* published by the Maine DEP, and available on-line at www.umaine.edu/WaterResearch/ FieldGuide/Field%20guide.pdf.

14. One of the clearest explanations we found of the Trophic State Index was on-line at dipin.kent.edu/tsi.htm.

15. The most up-to-date identification reference on regional aquatic and wetland plants is the two-volume

Aquatic and Wetland Plants of Northeastern North America by G.E. Crow and C.B. Hellquist. It was published in 2000 by the University of Wisconsin Press and recently came out in paperback.

16. The Invasive Plant Atlas of New England (IPANE) is available on-line at http://nbii-nin.ciesin.columbia.edu/ipane/

17. Our favorite butterfly book for the identification and ecology of East Coast butterflies is *Butterflies of the East Coast: An Observer's Guide* by R. Cech and G. Tudor. It was published in 2005 by Princeton University Press.

18. The two best regional amphibian and reptile books are, in our opinion, M.W. Klemens' *Amphibians and Reptiles of Connecticut and Adjacent Regions*, published in 1993 by the State Geological and Natural History Survey of Connecticut, bulletin No. 112, and the recently-published *The Amphibians and Reptiles of New York State* by J.P. Gibbs, A.R. Breisch, P.K. Ducey, G. Johnson, J.L. Behler and R.C. Bothner, published by Oxford and based in part on the NYS Herp Atlas.

19. A summary of amphibian declines in the "new world" is available at http://www.natureserve.org/ publications/disappearingjewels.jsp.

20. The United States Frogwatch web page is www.nwf.org/frogwatchUSA/. Canada also has a Frogwatch program at www.naturecanada.ca/cwn_naturewatch_fw.asp.

21. Aside from the book cited in note 12, the Metropolitan Conservation Alliance of the Wildlife Conservation Society has published a pair of useful management documents outlining the interaction of land use and vernal pool amphibians, these are, from 2004, *Habitat Management Guidelines for Vernal Pool Wildlife,* WCS/MCA Technical Paper No. 6, written by A.J.K. Calhoun and P. de Maynadier, and, from 2002, *Best Development Practices (BDPs): Conserving Pool-Breeding Amphibians in Residential and Commercial Developments in the Northeastern United States,* WCS/MCA Technical Paper No. 5, by A.J.K. Calhoun and M.W. Klemens. Also see the paper by Gibbs et al. cited in footnote 2, and the paper by A.D. Guerry and M.L. Hunter, Jr., entitled *Amphibian Distributions in a Landscape of Forests and Agriculture: an Examination of Landscape Composition and Configuration*, published in 2002 in the journal 'Conservation Biology', volume 16, pages 745-754.

22. The report which estimates the health effects of air pollution in the EU is a document of the UN Economic and Social Council entitled *2005 Joint Report of the International Cooperative Programmes and the Task Force on the Health Aspects of Air Pollution*, the document is coded EB.AIR/WG.I/2005/3. It available on-line at www.unece.org/env/wge /24meeting.htm.

23. More information on the New York State odonate survey is available at http://www.dec.ny.gov/animals /31061.html.

24. We found three books particularly useful for identifying dragonflies and damselflies and beginning to understand their ecologies: *A Field Guide to the Dragonflies and Damselflies of Massachusetts* by B. Nikula, J.L. Loose, and M.R. Burne, published without a date by the Massachusetts Natural Heritage Program; *The Dragonflies and Damselflies of Ohio* edited by R.C. Glotzhober and D. McShaffrey and published in 2002 by the Ohio Biological Survey; and Ed Lam's beautifully illustrated *Damselflies of the Northeast* published (with a lousy binding) in 2004 by Biodiversity Books.

25. The quotation comes from a web page on dragonfly conservation published by Scottish Natural Heritage, www.snh.org.uk/publications/on-line/naturallyscottish/dragonfly/Conservation.asp

26. A recent scientific paper supports the relevance of habitat structure for odonates but found that grazing decreased favorable structure and so reduced diversity. At least a couple of explanations might be possi-

ble for this seemingly contradictory result: 1) grazing may have been more intense at the sites studied by these authors, 2) (and perhaps most important) we compared grazed ponds to ornamental ponds, where as the cited paper compared grazed ponds to natural prairie pot holes. It is not difficult to suppose that grazed ponds are an improvement over mowed ones, while they are not as beneficial as natural prairie pools. The paper in question is *Odonates as Biological Indicators of Grazing Effects on Canadian Prairie Wetlands* by A.L. Foote and C.L. Rice Hornung published in 2005 in the journal ‘Ecological Entomology’, volume 30, pages 273-283.

27. See for example, the paper *Evaluating the Impact of Pollution on Plant-Lepidoptera Relationships*, published in 2005 in the journal ‘Environmetrics’, volume 16, pages 357-373. It was authored by C. Mulder, T. Aldenberg, D. de Zwart, H.J. van Wijnen and A.M. Breure.

28. The references referred to here are the same as those cited in note 2, along with references therein. The relationship between diversity and agriculture is not all love and roses, important negative relations exist, especially where agriculture is intensive and pesticide/herbicide use widespread. For example, the cited paper by Knutson *et al*., while concluding that farm ponds can be valuable for amphibians, provides some specific management suggestions for avoiding the negative farming influences that they observed (mainly associated with intensive grazing). Our central point is that here in the Northeast where most agriculture is relatively small-scale and the landscape is rapidly (sub)urbanizing, the profound negative effects of that development need to be adequately recognized and, in the face of those effects, the potential for relative synergy between agriculture and nature conservation should not be overlooked.

29. Aside from his manual (cited in footnote 3), G. Winfield Fairchild’s web page (darwin.wcupa.edu/ponds/management.html) is a good, practical starting point for pond management in our area. Cornell lists some additional web sites at fish.dnr.cornell.edu/Pond/ otherresources.htm?otherresourcesdoc.htm~mainFrame. Tom Matson has published a series of books on pond maintenance and construction. His works include *Earth Ponds*, *A Sourcebook for Earth Ponds*, and *Landscaping Earth Ponds*. Aside from considering the aesthetic and practical aspects of pond construction, he also discusses how to manage them in environmentally sound ways.

30. The full reference for the lakescaping book is *Lakescaping for Wildlife and Water Quality* by C. L. Henderson, C. J. Dindorf, and F. J. Rozumalski. It is not dated, but was published during the last decade by Minnesota Department of Natural Resources. It appears to still be in print, and we found a copy through an on-line bookstore. It abounds with helpful color photographs.