Effects of pond acidity levels on distribution of turtle populations at Black Rock Forest, NY
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ABSTRACT

Regional levels of high acidity in ponds and lakes are the result of wide-scale acid rain in the northeastern United States (Mason 1992, Likens 1996). Rain and snow in this region has had an annual pH of 4.05 to 4.3 since 1963 (Likens 1996), resulting in acidic ponds in areas such as Black Rock Forest. This research examines the effects of acidification on populations of painted turtles, (*Chrysemys picta*), and snapping turtles (*Chelydra serpentina*), in five different ponds of varying pH levels at Black Rock Forest, in New York State. Turtle foraging behavior, combined with sensitive hatchling development and a long life span, make them particularly vulnerable to habitat quality (McKnight 1993).

From June 5, 1997 to August 6, 1997, two types of data were gathered and correlated: data on pond chemistry, and data on turtle populations. Pond chemistry analysis includes dissolved oxygen and pH measurements, inorganic ion concentration and chlorophyll analysis. Results from the pond chemistry data confirm distinct differences in water habitat quality between the five ponds.

Turtles were trapped with funnel turtle traps, using two methods of marking. Electronic PIT tags (Camper 1988), were used for permanent marking of individuals, and shell notching (Cagle 1939), was used for easy short term identification and for juveniles. Blood samples were taken, and shell notches preserved, for future molecular genetic analysis. Data on sex, age, and size of turtles was recorded.

Turtle populations were estimated from mark-recapture data using both simple graph analysis, and the Petersen-Lincoln estimator (White 1982), assuming closed populations. Abundance estimates were weakly correlated with pond chemistry data: highly acidic ponds have lower turtle populations than more neutral habitats. Analysis of sex ratio data and age structure in each pond correlated further: ponds of high acidity and low turtle populations tended to have skewed sex ratios and age structures, indicating a less robust breeding population. Knowledge gained will aid Black Rock Forest in creating and maintaining stable pond habitats necessary to support turtle populations.

INTRODUCTION

IMPACT OF POND ACIDIFICATION

"Pond (or lake) acidification", as used here, refers to ponds with a pH less than 5.0. The detection of acidified ponds and lakes (most notably in the northeast and western United States, eastern Canada, Norway, and Sweden), is alarming, and requires further scientific study to determine cause of acidification and affect on regional ecosystems. Causes of widespread pond acidification are thought to be largely anthropogenic. Declining agricultural practices, declined grazing, deforestation, and prevention of naturally occurring forest fires all allow for accumulation of acid in soil and ground water, ultimately collecting in ponds and lakes (Mason 1992). Increased industrialization resulting in acid rain has long been suspect as a cause of pond acidification

(Mason 1992). In the northeast United States specifically, acid rain is thought to be the main cause of pond and lake acidification. "Normal" rainfall has a theoretical pH of 5.6, assuming equilibrium with atmospheric carbon dioxide (Weiner 1992). Average pH of rainfall in the northeastern United States has been over 15 times more acidic, with an annual average of 4.05-4.3 since 1963 (Likens 1996). Studies of acidified ponds have shown significant correlations between low pH levels and decreased biological diversity.

The degree of pond acidification may potentially affect the structure of the biological community by eliminating acid intolerant species (Locke 1992). By removing members of the ponds' food chain, the chain is disrupted and the entire community is affected. Studies on zooplankton (Locke 1992, 1994) and fish (Weiner et.al 1984) in eastern North American lakes, show species richness decreases significantly as pH levels drop below 5.0. Amphibians as a group appear much more acid tolerant, though there are definite taxonomic, geographic, genetic, and environmental variations (Pierce 1985). This evidence demonstrates different ranges of tolerance and adaption ability among different animal groups, with reptiles largely unstudied in natural environments.

Studies by Locke (1992, 1994) show pH controls zooplankton community structure in Ontario province lakes with pH less than 5.0, at which point species richness and number of predatory links significantly decrease. However, diverse zooplankton populations appeared to return as lakes became less acidic over a 20 year study (Locke 1994). Since zooplankton occupy such a low level of the food chain, it might be expected that an alteration of the community structure at this trophic level would affect larger organisms dependent on them as a food source.

Weiner et.al. (1984) compared richness of fish species in two Wisconsin lakes, one with pH 6.7-7.5, termed neutral, and one with pH 5.1-6.0, termed acidic. They found that as pH approached 5.0, species richness was significantly lower, with only 5-11 species found in acidic lakes, compared with 10-17 species found in more neutral lakes. This decrease in species richness again has the potential to alter community structure because it results in less variable food resources. Carnivores and foragers at higher trophic levels may require diverse food sources not available in a habitat with a low species diversity.

Comparative studies of frogs inhabiting New Jersey lakes suggest acid tolerant species may be genetically adapted to their acidic environments. Species of frogs studied were found to exist in two general categories: those that tolerated acidic environments, and those that lived only in neutral environments (Pierce 1985). This suggests species may adapt to survive over time. Variations in amphibian acid tolerance may reflect variations in the natural, long term acidic environments, where those species evolving in acidic habitats are more likely to survive there. Knowledge of acidity effects on a given species are best understood when detailed knowledge of the species' ecology is available.

TURTLES

Painted turtles are the best studied freshwater turtle in the world, with four subspecies recognized in the United States. The northeastern subspecies, *Chrysemys picta picta*, is distinguished by a yellow colored bottom shell, or plastron (Ernst 1989). Males have elongated foreclaws and slightly smaller shells than the females, with a large female having a shell length of 200mm (Harless and Morlock 1989). *Chrysemys picta* are avid diurnal baskers, emerging in the morning to bask and forage, then basking in the afternoons, and foraging again before retiring to

the bottom of the pond to sleep during the night (Ernst 1989).

Large snapping turtles, *Chelydra serpentina*, are twice the size, males growing larger than females, with a shell length of 400mm (Harless and Morlock 1989). *Chelydra serpentina* are largely aquatic, spending most of their time during the day on the bottom of the pond or in shallow areas with nostrils exposed, becoming more active at night (Ernst 1989).

Populations of *Chrysemys picta* and *Chelydra serpentina* were found in each of the five ponds trapped at Black Rock Forest. Two, female, red-eared sliders (*Trachemys scripta*), were caught in one of the ponds where they had been previously observed by Forest Manager John Brady (personal communication). The sliders are thought to be abandoned pets because they are not indigenous to the area, but thus far provide no evidence of breeding.

The Black Rock Forest area encompasses the home range of other freshwater turtle species: the common musk turtle (*Sternotherus odoratus*), bog turtle (*Clemmys muhlenbergii*), blanding's turtle (*Emydoidea blandingii*), the common map turtle (*Graptemys geograptica*), and the eastern mud turtle (*Kinosternon subrubrum*), are all documented as residing in the northeast United States (Conant 1991), but were not observed in the study area. Shells of the wood turtle (*Clemmys insculpta*), have been found at Black Rock Forest (Bill Schuster, personal communication), and both the spotted turtle (*Clemmys guttatta*), and the eastern box turtle (*Terrapene carolina*), have periodically been observed, but were not successfully trapped or observed during this study.

Turtles are tertiary level feeders (Harless and Morlock 1989), foraging as both omnivores and carnivores, and depending on a wide range of food sources to sustain themselves, including aquatic plants, fish, and small crustaceans. When food resources are limited, foraging for food becomes increasingly difficult for turtles, who spend over half of their waking hours in search of food. They commonly have long life spans in the wild, living up to 25+ years of age (Gibbons 1987), and migration between ponds in close proximity has been documented for painted turtles in New York State (Zweifel 1989). Turtles hibernate in winter months, emerging in May-June to mate and nest, with eggs hatching in August-September (Ernst 1989, Zweifel 1989). Hatchling sex is dependent on nest temperature during development, but the sex produced at a given temperature varies between species (Ernst 1989). In both painted and snapping turtles, warmer mean temperatures during the early stages of development (>27 degrees Celsius) are more likely to produce females, and colder temperatures (<27 degrees Celsius) are more likely to produce males (Janzen 1991). Sex ratios are therefore greatly influenced by environmental conditions.

Because turtles forage regularly, have long life spans, are sensitive to environmental changes as hatchlings, and are known to reside at Black Rock Forest, they provide an ideal subject to study the affects of pond acidity.

IMPACT OF POND ACIDIFICATION ON TURTLES

Impact of pond acidification on turtles is largely unknown; no studies exploring the effects of acidification on turtles in natural habitats have been published. As in amphibians, different species may have different pH tolerance levels. This would result in lower population abundance or elimination of the species from an area entirely. Population structure within the pond could be greatly impacted if young, old, male, or female turtles have different levels of tolerance. An excess of tolerant individuals might be found, while the less tolerant would be absent or less abundant.

Pond acidification may also greatly impact turtle foraging, migration, and nesting

behavior. Food availability may decrease as ponds acidify and become less diverse, inducing turtle migration in search of an adequate food supply. The affect of pond acidity on vegetation abundance will alter the environment of nesting sites. Because hatchling sex is determined by nesting temperature during development, the lack of vegetation cover due to acidity may alter nesting site temperatures via more solar radiation (Janzen 1994), resulting in a skewing of hatchling sex ratios. Many aspects of turtle ecology could be potentially affected by pond acidification.

STUDY AREA

Black Rock Forest is a 1500 hectare wildlife preserve located approximately 37 kilometers north of New York City in the Hudson Valley. In this study five distinct ponds were surveyed, varying in surface elevation from 310m to 400m, and in yearly average pH from 4.5 to 6.0 (Adirondack Lake Survey 1987). Pond size varies from 3 to 7 hectares, and 2.5 to 7 meters in depth, with each pond displaying slightly different vegetation and animal diversity. Four of the ponds in this study (Tamarack, Sphagnum, Arthurs, and Aleck Meadow), were constructed as water storage reservoirs for the village of Cornwall between 1920 and 1935, and function as a combined water system currently providing the town's main water supply.

Ponds found at higher elevations have the lowest pH levels presumably because upper areas of the watershed catch acid rain directly, while ponds at lower elevations receive acid rain runoff that has been buffered by soils and vegetation (Schuster, personal communication). Immediately following precipitation, pH levels of Tamarack may fall to as low as 3.9, and remain low for approximately 24 hours (Schuster, personal communication). Pond data are given below, based on information from The Adirondack Lake Survey done in 1987, and Bill Schuster, Black Rock Forest Director.

POND	AVG pH	ELEVATION	AREA	MAX DEPTH	HISTORY	DIST FROM SUTHERLAND
Tamarack	4.5	398m	7.3ha	2m	built 1926	0.7km
Sphagnum	4.8	381m	6.9ha	6m	built 1926-27	0.2km
Sutherland	5.3	380m	4.1ha	2.5m	natural	0km
Arthurs	5.8	375m	5.8ha	7m	built1920-22	1.4km
Aleck Meadow	6.0	314m	3.0ha	7m	built 1910-15	2.1km

Sutherland pond is approximately 12,000yrs old Adirondack Lake Survey 1987), and is the only natural pond among those studied. Both Sutherland and Sphagnum feed adjoining swamps and are at the same elevation, but differ drastically in age and size, providing an interesting comparison of turtle habitats. All five ponds are within close proximity to each other, and no records of stocking the ponds with turtles are known to exist. It is plausible that all the turtle populations in the area originated from Sutherland pond, indicating that turtle movement between the five ponds is possible, though distances between ponds vary considerably, as illustrated on the map (Figure 1).

METHODS

TURTLE DATA

Chrysemys picta and *Chelydra serpentina* were trapped and tagged daily from June 5 to August 6, 1997. During the week of July 3 to July 10, traps were removed, cleaned, and replaced in new locations within each pond. Turtles were trapped using hoop nets as described by Ream and Ream (1966). Metal crawfish traps were used in swampy areas in an effort to catch the more terrestrial species. Each pond had 3 hoop nets and was checked once every 24 hours. Sardines in oil were most commonly used as bait and replaced once a week. Fisherman's oil, tuna fish, and cat food, were also used periodically as additional bait, but never as a replacement to the sardines.

To determine age structure and individual growth patterns, the mass, age (via growth ring counts described by Sexton 1959), and plastron length were recorded for each individual captured. Mass was recorded to the nearest gram, and all length measurements were made visually with a plastic ruler. Older individuals could not be accurately aged because individual growth rings were worn beyond distinction. These individuals were recorded only as "worn". *Chrysemys picta* individuals were classified as juveniles when the plastron was less than 100mm in length (Figure 2a). *Chelydra serpentina* individuals were classified as juveniles when the plastron length was less than 200mm (Figure 3). Both the number of juveniles found in each pond, and the plastron and mass measurements were used as indicators of overall population health. Mature females three years of age and older were physically checked for the presence of eggs by feeling anterior to the base of the rear legs and holding the individual in a vertical position (to allow any eggs present to drop down). Presence of eggs was recorded.

Two measurements were taken to determine the sex of each turtle captured. The total length of the tail from the plastron to the tail tip was compared to the distance from the cloaca (an opening in the tail for the reproductive and excretory systems) to the tail tip, each measured to the nearest millimeter with a clear ruler. The cloaca of females is closer to the plastron than on males, and the ratio of the two measurements was used to determine sex.

If the cloaca:tip length was over 70% of the total length of the tail, the individual was sexed as a female. In *Chrysemys picta*, this ratio was confirmed by a third measurement: males display long, sexually dimorphic third claws on their front feet. A third claw length over 10mm on a sexually mature individual at least three years of age, indicated a male. Figure 3a illustrates the correlation of the claw measurement and the cloaca:tip ratio for adults. The two clusters of points represent females and males. The tail length ratio and third claw measurement were consistent in determining sex in all but 16% of the captures of *Chrysemys picta* adults. When the two methods assigned different sexes to the same individual, the sex predicted by the cloaca:tip ratio was used in summarizes pond sex ratio data. Claw length may vary among males; because of this variability, the tail measurements were used as the default when sex was not clear. Juveniles of neither species were sexed, though all measurements were taken.

In *Chelydra serpentina* confirmation of accurate sex determination is difficult. Males typically have larger plastrons than females (Harless and Morlock 1989), so a graph of the tail:tip ratio and plastron length should show clusters of sexually dimorphic females and males of different sizes. However, Figure 3b illustrates an unclear distinction among female and male *Chelydra serpentina*. This is likely a natural consequence of the diverse structure of the

populations trapped; but there is no estimate of error for sex determination.

Turtles were marked using electronic PIT tags (AVID, 10mm in length), as described by Camper (1988), and identified in the field with a hand held scanner. This process involved injecting a small, glass, non-electric, bar coded chip, under the turtles' skin. PIT tags were uniformly placed under the rear left leg for quick scanning and identification, and were tested for reliability prior to injection. Once in place, PIT tags are permanent marks that can be used to identify individuals in future studies. Juvenile painted turtles with a plastron less than 100mm were not PIT tagged due to their small size. The carapace of all captured turtles was notched (as described by Cagle 1939), to both provide a marking system for juveniles, and a back up in case of PIT tag failure. All notch pieces were preserved in alcohol for future molecular genetic analysis of the turtle populations at Black Rock Forest. Further, blood samples were collected in the field for DNA analysis by Michael Forester, University of Florida.

All turtles were released at the point of capture after being marked and measured. Throughout the study period, recaptured individuals were not re-measured, but females determined to be gravid upon initial capture were examined for eggs upon recapture. Mark-recapture data was statistically analyzed using the Peterson-Lincoln estimator (White 1982), and graphs of cumulative catch over time. The Petersen-Lincoln calculations assume a closed population (no birth, death, immigration or emigration), and equal capture and recapture probabilities throughout the study period. Calculations were based on the following equation.

$$N = \frac{(n1)(n2)}{m2}$$

Where N is the estimated population, n1 is the number of animals caught on the first capture occasion, n2 is the total number of animals caught on the second capture occasion, and m2 is the number of marked animals caught on the second trapping occasion. This equation assumes the ratio of marked:unmarked animals caught on a single occasion is equal to the total number of marked:unmarked animals in the total population. Because the number of turtles recaptured during this study was low, data is summed over a week long period to generate estimates, where a trapping occasion=trapping over one week.

POND CHEMISTRY DATA

Water acidity measurements were taken approximately every two weeks at each trap location in the five ponds using a hand held pH meter within 0.5m of the water surface. Hydrogen ion concentration was then used as a water quality parameter to compare the different ponds. A hand held, electronic thermometer was used to take water temperature readings whenever any samples or measurements were taken.

To better understand plant productivity in the ponds, both dissolved oxygen measurements and chlorophyll samples were taken. Dissolved oxygen measurements were taken at dawn and dusk to compare the effects on dissolved oxygen in the water from both phytoplankton and macrophytes. Because of the presence of photosynthesizing plants in the ponds, oxygen levels are typically higher in the evening, after solar energy has fueled carbon dioxide consumption and oxygen release. Differences in daily oxygen cycling between ponds serve as an indication of the amount of photosynthesizing plant life present and allow for further comparison of the different

turtle habitats. Dissolved oxygen samples were analyzed using the Winkler titration method (Winkler 1888), at Black Rock Forest.

To help distinguish between the effects of the phytoplankton and macrophytes, chlorophyll samples were filtered and frozen for analysis at Lamont-Doherty Earth Observatory. The amount of chlorophyll in the water is related to the abundance of phytoplankton present. Pond water samples of a known volume were filtered, trapping any particulates in the water on a standard GFF filter, and immediately frozen away from any light. Chlorophyll was later extracted from the filter using 90% Acetone and read using a fluorometer. The amount of chlorophyll present was calculated from the level of florescence. The chlorophyll content of the water indicates how abundant the phytoplankton are in the water: more chlorophyll indicates more phytoplankton. Because phytoplankton are essentially the base of the food chain, chlorophyll measurements allowed for comparison of overall pond health.

RESULTS

TURTLES

A summary of mark-recapture, sex ratio, and age structure data for each pond are given in Table 1. Aleck Meadow and Sutherland ponds appear to have the most abundant and healthy *Chrysemys picta* populations, with an excess number of potentially breeding females and the presence of juvenile populations. In comparison, the other three ponds had much lower trapping success, implying a much lower turtle population density. Data from Tamarack, Arthurs, and Sphagnum reveal a lack of young individuals, while Sphagnum may have a deficiency of females.

Low capture frequencies of *Chelydra serpentina* indicate those populations are much lower than *Chrysemys picta* populations, with a maximum of 18 snappers trapped in Sutherland pond, over 50% of which were juveniles. With such a low number of captures, determining the significance of sex ratio data is difficult, but Sphagnum clearly has a deficiency of females again, with only one snapper caught identified as female.

CAPTURE SUCCESS

Turtle abundance can be visually estimated from graphs presented in Figures 4a-4b. "Cumulative captures" refers to the number of new individuals caught on each trapping day. As the slope of the line approaches zero (no new individuals are captured), it is assumed that most (if not all) of the population has been trapped and marked. These values represent minimum population sizes that are likely close to the actual population. The graphs for Tamarack, Sphagnum, and Arthurs, show both the populations of *Chrysemys picta* and *Chelydra serpentina* have been essentially "trapped out" (slope of the line equals zero), indicating that all the turtles living in those ponds were marked. *Chrysemys picta* population estimates in Aleck Meadow and Sutherland ponds can be made by visually extending the curves, indicating populations of over 80 and 45 respectively.

Estimation of *Chelydra serpentina* populations from graphs of cumulative captures over time are more tentative due to the low number of turtles captured. Both Arthurs and Tamarack show no new captures during the last week of trapping, indicating very low populations in each of those ponds. The appearance of new individuals in Sphagnum was slow but consistent, with

approximately one new snapper caught each week, making simple population estimation difficult. Aleck Meadow seems to have a deficiency of *Chelydra serpentina* in comparison to its *Chrysemys picta* population, with a majority of juveniles. The fact that cumulative capture of new individuals was steadily rising, combined with a healthy presence of young snappers, may indicate the existence of a larger population of *Chelydra serpentina* than is apparent from the trap out graph. Cumulative captures in Sutherland pond have also been consistently rising, displaying the largest *Chelydra serpentina* population of the five ponds. There are likely to be more than 20 snapping turtles in Sutherland pond.

POND CHEMISTRY

The averages of pond chemistry data collected over the study period are summarized in Table 2. Ponds at the highest elevations clearly show the highest level of hydrogen ion concentration, indicating highly acidic waters. However Sutherland and Sphagnum differ in elevation by only one meter, yet have drastically different concentrations of [H+]. Sutherland also shows much greater levels of chlorophyll than any of the other ponds. Distinguishing characteristics of Sutherland are most likely due to the fact that it is a natural pond, substantially older, with more established biological populations, and exists as a separate water system. The other four study ponds exist as one water system: Tamarack drains into Sphagnum, Sphagnum drains into Arthurs, and Arthurs drains in to Aleck Meadow. Tamarack clearly shows the largest diurnal oxygen cycling, with Arthurs maintaining the lowest.

Appendix 1 details dissolved oxygen measurements, dates, and saturation values, at recorded temperatures. Appendix 2 contains dates of chlorophyll sampling, as well as inorganic pond chemistry measurements analyzed by Julie Nichols of Lamont-Doherty Earth Observatory. Appendix 3 provides daily pH measurements and examination of changes over time.

MARK-RECAPTURE POPULATION ESTIMATES

The estimate of turtle populations using the Peterson-Lincoln equation (White 1982), are presented in Table 3. All calculations assume a closed population, and weekly data was summed to obtain estimates. The absence of an estimate resulted from a week where no recaptures occurred, rendering the Peterson-Lincoln estimator unsolvable. Densities are calculated based on surface area data collected by the Adirondack Lake Survey, 1989, detailed in the . description of the study area. Standard deviations are calculated for statistical comparison.

Both the Peterson-Lincoln estimates and the graphs of cumulative captures clearly show Aleck Meadow has the highest population of *Chrysemys picta*. Sutherland pond has the highest population of *Chelydra serpentina* possibly because the population has been established there longer than in the other ponds. Population estimations for Sphagnum, Arthurs, and Tamarack are all much lower.

DISCUSSION

The estimated turtle populations and densities determined from this study appear to fall into two categories: very small populations (Tamarack, Sphagnum, and Arthurs), and large

populations (Sutherland and Aleck). The differing population estimates likely result from a number of environmental and internal factors, divided into two groups for this study: water chemistry and population characteristics. For each pond, turtle populations are first compared with water chemistry data, (as illustrated in Figures 5a-6c), and second with population characteristics such as age, sex ratio, and overall abundance, (as illustrated in Figures 7a-8b). The correlation coefficients presented in Table 4 illustrate the relationship between pond chemistry data and estimated turtle populations. The column entitled "*Chrysemys picta* without Aleck", shows calculated correlation coefficients for *Chrysemys picta* with the exception of Aleck Meadow. Because the population in Aleck Meadow is significantly larger than in the other ponds, the correlation between pond chemistry and turtle abundance is sometimes stronger when Aleck is considered an unusual and separate case study. A strong correlation is indicated by numbers closer to 1, values close to zero indicate a poor correlation. Data are analyzed by pond in order of draining; with the exception of Sutherland, ponds of higher elevation drain in to those at lower elevation.

TAMARACK

At the highest elevation of the five study ponds, Tamarack clearly has the most acidic waters, but not the lowest turtle populations. Chlorophyll data indicate a moderate abundance of phytoplankton, but with the largest diurnal cycle of dissolved oxygen found at Black Rock Forest. These data are consistent with the appearance of the pond: the water is comparatively clear (moderate levels of phytoplankton), but macrophytes are abundant (much photosynthesis and hence large oxygen cycles). High acidity levels may influence the diversity and abundance of the biological populations in Tamarack, but it clearly does not eliminate a functioning food chain, complete with both *Chrysemys picta* and *Chelydra serpentina*.

Trapping data reveal a slight bias towards female *Chrysemys picta*, but slightly more male than female *Chelydra serpentina*. Because the total number of captures for *Chelydra serpentina* is low, it is difficult to determine if Tamarack suffers a deficiency of female snappers, but it is possible population densities are limited by a lack of breeding females. For both species, less than 25% of turtles captured were juveniles, (with no juvenile snappers), indicating either poor breeding success or low survival rates of young. Visually comparing the five ponds, Tamarack does not appear to lack adequate nesting sites, with both an accessible dam and island for females to haul out and dig nests. This may suggest turtle populations are limited by either a lack of breeding pairs, or low juvenile survival.

It is unknown exactly how acidity affects turtles, particulary juveniles. Though Tamarack appears to have healthy phytoplankton and plant populations, adequate sex ratios, and adequate nesting sites, populations remain low. Lack of juveniles suggests that low acidity may affect survival rates of young turtles, though firm conclusions require further study.

SPHAGNUM

Sphagnum is nearly as acidic as Tamarack, although with quite low levels of chlorophyll and high mean oxygen levels, with a small diurnal cycle. Chlorophyll and oxygen data are consistent, but the diurnal cycling of oxygen is low due to the lack of chlorophyll over such a large volume. Again this can be visually confirmed: the water is extremely clear in Sphagnum (low phytoplankton). The large perimeter of the pond is cluttered with bushes, trees, and shrubs that

overhang into the water.

Sphagnum has the lowest density of *Chrysemys picta*, and the second lowest density of *Chelydra serpentina*. The lack of phytoplankton could indicate the absence of an adequate food chain, and hence the absence of an adequate food supply for turtles. It is unlikely that acidity limits phytoplankton because Tamarack is just as acidic, yet maintains a moderate concentration of primary producers. Turtle populations at Sphagnum are more likely limited by the ability to breed. Both *Chrysemys picta* and *Chelydra serpentina* are deficient in females and juveniles. This may result in a deficiency of breeding pairs, low reproduction, and consequent low population densities.

The quality of the nesting sites could account for the male biased sex ratios. As stated the perimeter of Sphagnum is heavily vegetated and also has very steep banks. Because turtle sex is dependent on incubation temperature of the nest, a heavily vegetated nesting area could result in cool nesting temperatures, and hence production of a male majority. Janzen (1994), suggests vegetation cover can affect nesting temperature, and hence provide a mechanism of choice for gravid females. A mother wishing to produce females would choose an open, sunny site where temperatures will be warmer. However, the steep banks of Sphagnum may limit female movement to more variable nesting conditions, resulting in skewed sex ratios and consequent low population densities.

SUTHERLAND

As the only natural pond in this study, Sutherland has a relatively neutral level of acidity, and has both the highest concentration of chlorophyll and a comparatively large diurnal cycling of oxygen. Visually, Sutherland's waters are murky, muddy, and vegetated (lillipads, algae, other macroscopic plants), distinctly different from any other pond at Black Rock Forest. Populations densities of snapping turtles are highest at Sutherland, and population densities of painted turtles at Sutherland are second only to Aleck Meadow. Sex ratios are clearly even, and more juveniles were captured in these two ponds than in the other three combined. This indicates a very healthy population of turtles: able to mate, nest, and survive the critical hatchling years. Because none of the ponds at Black Rock Forest were stocked with turtles, it is likely that all the turtles in the four manmade ponds originated from Sutherland populations.

The abundance of phytoplankton, (indicated by chlorophyll data), and the presence of a variety of plants, (indicated both by dissolved oxygen diurnal cycles and visual observations), clearly appear to aid the support of healthy turtle populations. Because the pond is more than 10,000 years old, a diverse plant and animal community has been established and maintained.

Sutherland and Sphagnum are essentially at the same elevation, yet have significantly different acidity levels, indicating that elevation is not the only control of the pH of these ponds. Sutherland is fed continuously by underground springs that bubble in cold water at depth, but little is known of the chemistry of these waters (Schuster, personal communication).

ARTHURS

Arthurs maintains a more alkaline acidity level, a moderate chlorophyll concentration, and moderate dissolved oxygen levels and diurnal cycling, yet has extremely low turtle population densities. Arthurs is unusual in that it has been periodically drained entirely by the Cornwall Water Department. During the summer of 1996 the dam was accidently left open and the pond dried

completely (Schuster, personal communication). In the case of Arthurs pond, the extremely low turtle populations could be the result of a mass emigration following the draining. During a similar study of *Chrysemys picta* residing on an estate on Long Island, New York, Zweifel (1989), reported turtle migration away from dried out ponds. Arthurs low population densities are likely due to a recent emigration.

Without the periodic, complete drainings, one may expect Arthurs to be home to healthy turtle populations. Acidity levels are similar to Sutherland Pond, which has healthy populations of both *Chrysemys picta* and *Chelydra serpentina*, and the pond clearly supports a moderate phytoplankton community. Instead, Arthurs pond exhibits extremely low turtle populations. With roughly even sex ratios of *Chrysemys picta*, and an excess of female *Chelydra serpentina*, both species still lack juvenile populations. Breeding pairs may be present but unsuccessful at raising juveniles due to poor nesting conditions or low survival rates of the young. In this case, even if a female successfully nested in the past, the drying of the pond may have increased the mortality rate of her offspring, resulting in the lack of juveniles evident from the trapping data.

Before this study, *Chrysemys picta* were not thought to inhabit Arthurs pond. We now know they are present, but at a low density. A *Chelydra serpentina* individual was observed attempting to dig a nest on the dam at Arthurs pond, but she quickly abandoned the site without laying eggs. Lack of adequate substrate for nesting may be a factor for all nesting sites at Black Rock Forest. The soil is very hard, making deep nests difficult to dig, and shallow nests more likely to be predated.

ALECK MEADOW

As the lowest elevation pond, Aleck Meadow has the most neutral level of acidity, and by far the highest concentration of *Chrysemys picta*. The average chlorophyll concentration is second only to Sutherland pond, with a moderate dissolved oxygen diurnal cycle. Aleck Meadow is the farthest pond from Sutherland included in this study; if all the turtle populations in Black Rock Forest originated from Sutherland, migration distance was apparently not the controlling factor in distribution. Concentration of turtles is not centered around Sutherland pond, as might be expected if migrations distance was a controlling factor. Aleck Meadow habitat clearly supports an adequate food chain for turtles, with a diverse number of species present. Visually, organisms were observed at Aleck that were not observed in the other ponds (most notably: leeches).

Clearly *Chrysemys picta* find Aleck Meadow a good habitat: there is an excess of breeding females, and many juveniles are present. Nesting sites around Aleck Meadow are not obvious, but the habitat appears more variable than the other study ponds, (flat, steep, open, vegetated, hard substrate, soft substrate). Aleck Meadow *Chrysemys picta* have either a yellow or a red plastron. All other *Chrysemys picta* captured at Black Rock Forest during this study possessed yellow plastrons. Perhaps this characteristic indicates a greater genetic diversity among Aleck *Chrysemys picta*, and hence a healthy and diverse breeding population.

Chelydra serpentina are not abundant in Aleck Meadow, but 50% of those captured were juveniles. It is likely the population of *Chelydra serpentina* in Aleck Meadow will increase given time to reproduce. The abundance of juveniles indicates nesting and survival rates are not the problem, only lack of breeding adults. As the juveniles reach maturity, the population of *Chelydra serpentina* in Aleck Meadow is likely to increase.

TURTLE MIGRATION

A single snapping turtle was documented moving from one pond to another. The female *Chelydra serpentina* 016, was originally captured in Tamarack, and recaptured 3 weeks later in Sphagnum. It is probable turtle 016 traveled down the stream connecting the two ponds because it was recaptured in a trap directly in front of the stream entrance to Sphagnum. No other instances of turtle migration were seen. Perhaps they simply do not migrate regularly, or were otherwise occupied with seasonal mating and nesting activities.

Movement of both painted and snapping turtles within each pond varied by individual. Some turtles were captured in one trap and subsequently recaptured in different traps, while certain individuals were captured and recaptured repeatedly at the same trapping location. No influence of sex or age was apparent.

ALECK MEADOW RECAPTURE

Estimates of yearly turtle recapture rates were calculated for Aleck Meadow painted turtles using data from a previous mark-recapture study. Black Rock Forest Manager, John Brady, trapped turtles in Aleck Meadow using similar hoop nets and sardine bait on the weekends of May 5, June 1, June 16, September 7, 14, and 21, of 1996. Traps were placed on Friday evening, checked once Saturday and once Sunday, and removed Sunday evening. A total of 80 painted turtles were marked with shell notches. This included 15 juveniles, 34 females, and 31 males, as is illustrated in Figure 9 as "1996" data. Using the Petersen-Lincoln estimator (White 1982), calculations estimated a population of 203 *Chrysemys picta* from 1996 trapping data. This estimate is compared to 1997 population estimates, shown in Table 5.

A third estimate of Aleck Meadow *Chrysemys picta* populations can be made by using 1996 capture data, and 1997 recapture data; effectively combining the two studies. Figure 9 shows the percentage of Aleck Meadow turtles that were marked in 1996, and recaptured in 1997. Seven juveniles, 5 adult males, and 10 adult females were recaptured in 1997. Using the Petersen-Lincoln equation again, a third population estimate is calculated and presented in Table 5 for comparison.

Survival rates are unexpectedly the highest for juveniles, and very low for both adult females and males. Adult turtles may learn to avoid the unwanted stress associated with the traps, and avoid recapture better than juveniles. It is unlikely that recaptured individuals were not identified as previously marked. Marks made by John Brady in 1996 were substantial and consistently visible in 1997.

TURTLE BEHAVIOR

Recapture rates were sufficient but not as high as expected, and were not sex or age biased (males were not recaptured more often than females, etc.). Capture rates of males and females did not appear to vary seasonally for male or female *Chrysemys picta* in Aleck Meadow and Sutherland; both sexes were caught at similar rates over the 2 month trapping period. Estimation of the populations using the Petersen-Lincoln equation assumes capture and recapture probabilities are equal throughout the study period. No obvious variations in these probabilities was detected in terms of sex, seasonal activity, precipitation, or temperature. However it is apparent that capture/recapture probabilities vary by individual. Table 6 shows some individuals

were recaptured more often than others; varying from a maximum of 4 recaptures per individual, to no recaptures.

SIGNIFICANCE OF RESULTS

The acidity level of ponds at Black Rock Forest is one factor affecting the density of turtle populations, but is clearly not the only factor. More likely the pH level affects the entire pond community including the plants, plankton, and herbivores, influencing the turtle population densities in the different pond habitats. How pond chemistry affects the population structure is unclear and worthy of further study. Habitat quality resulting from the chemical composition of the pond could indirectly be limiting turtle abundance by altering nesting site temperatures (controlling vegetation cover), limiting food resources, or decreasing survival rates.

Controlled laboratory experiments are necessary to determine the specific affects of pond chemistry (such as hydrogen ion concentration), on turtles. Turtles missing feet, tails, claws, and scutes, were found in every pond; but appeared in higher concentrations in the more acidic ponds, as illustrated in Table 7. Higher rates of deformed turtles in Tamarack, Sphagnum, and Arthurs (*Chelydra serpentina* only), could be a result of the small sample size compared to Sutherland and Aleck, but the trend indicates a need for further study.

Deformation could also be due to attempted predation; if so, turtles in the more acidic ponds appear to be escaped prey items more often than those in Sutherland and Aleck. Increased predation could be the result of less availability of food resources in the more acidic environments, but further study is needed. Other than extreme malformation, turtles in highly acidic ponds showed no difference in plastron length or mass, indicating normal growth patterns in adults.

FUTURE MANAGEMENT

Black Rock Forest is a potential home range to many species of freshwater turtles, yet only two native species were successfully trapped or observed during this study. Conclusions drawn from this study are as follows:

1. Sutherland Pond and Aleck Meadow both have close to neutral acidity levels and maintain healthy, breeding, turtle populations.

2. The two most acidic ponds, Tamarack and Sphagnum, maintain low turtle populations with skewed sex and age structures.

3. Arthurs pond, which remains close to neutral in acidity, has been an unstable environment in recent years, and hence is home to very few turtles.

Support of future research efforts to understand exactly how pond acidification affects turtle populations is vital. The most critical role for Black Rock Forest Managers in coming years is to maintain pond environments that are both chemically and physically stable. Future observation of the identified small populations will be critical as turtles either breed successfully, migrate, or die out. It is clear from this study that pond acidity is one factor associated with low

turtle densities, skewed sex ratios, and lack of juveniles, but causal mechanisms are not understood. Only by understanding the habitat requirements of these species, will managers be able to provide the necessary habitats for their survival in the long term.

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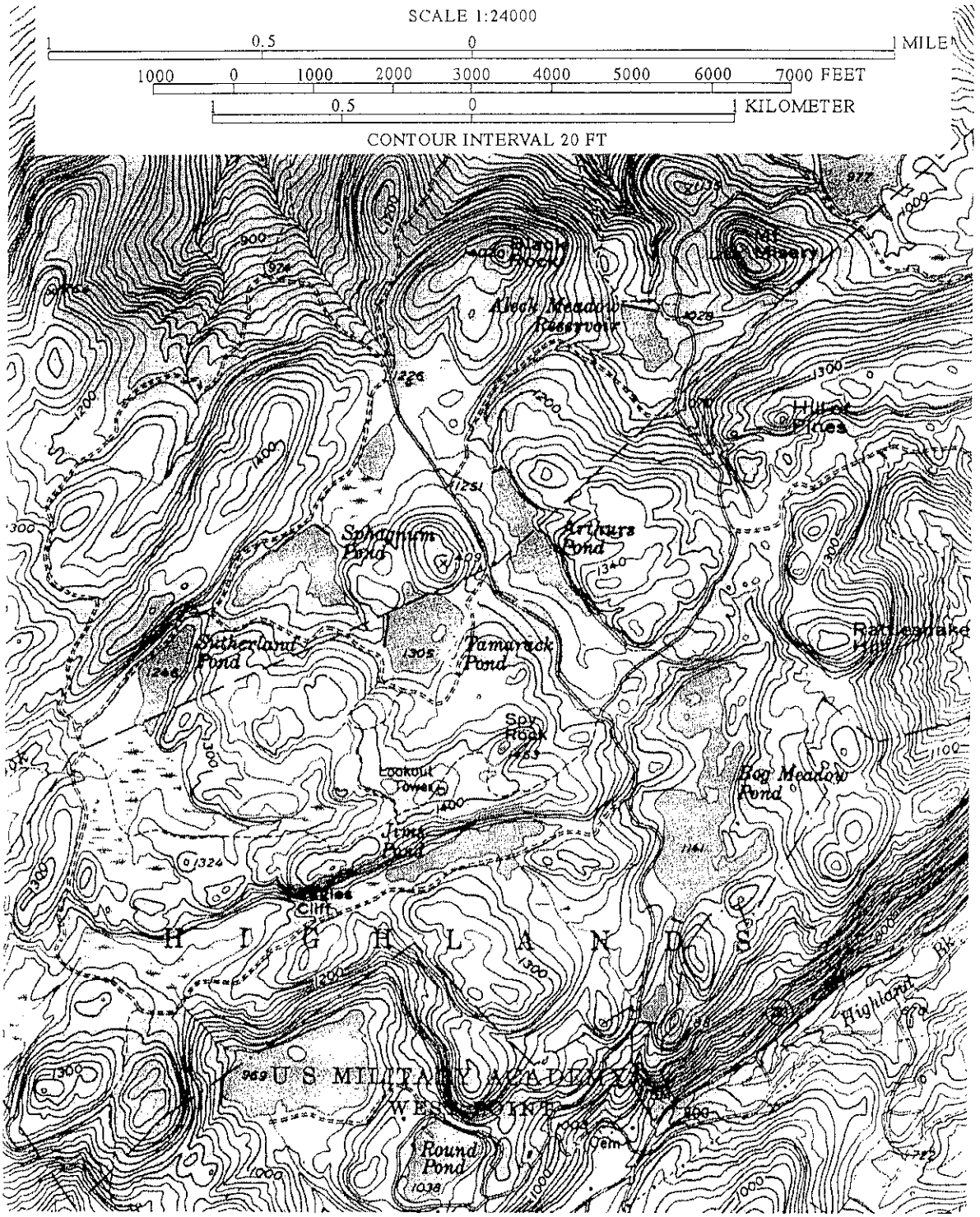

Figure 1

USGS Topographical map, Cornwall, New York.

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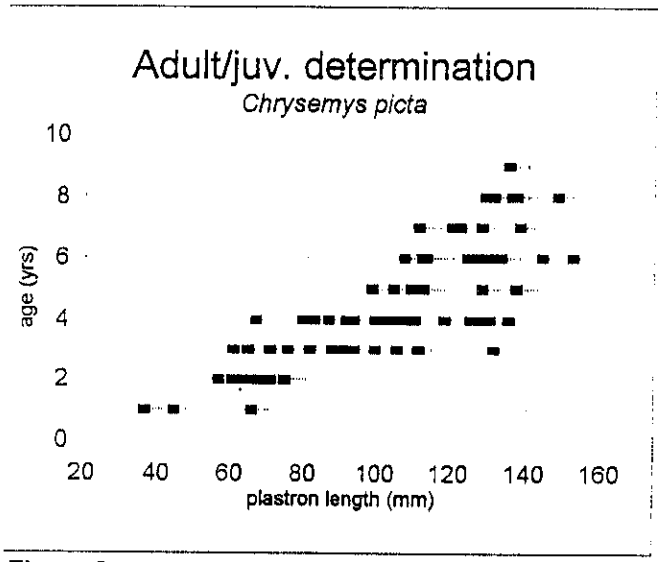

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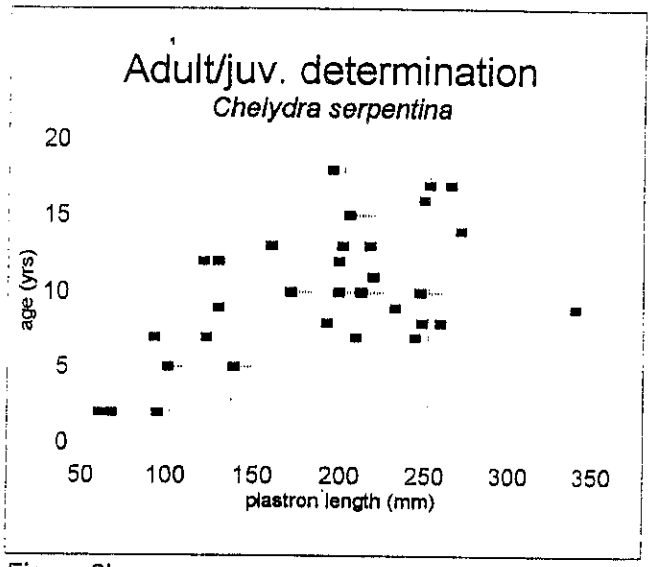

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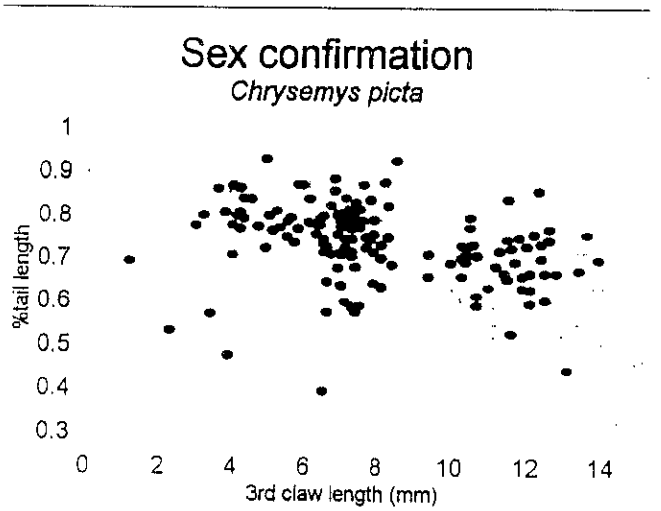

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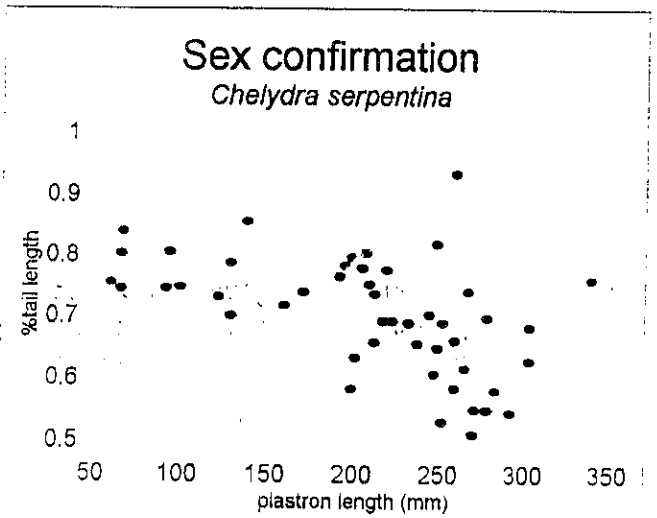

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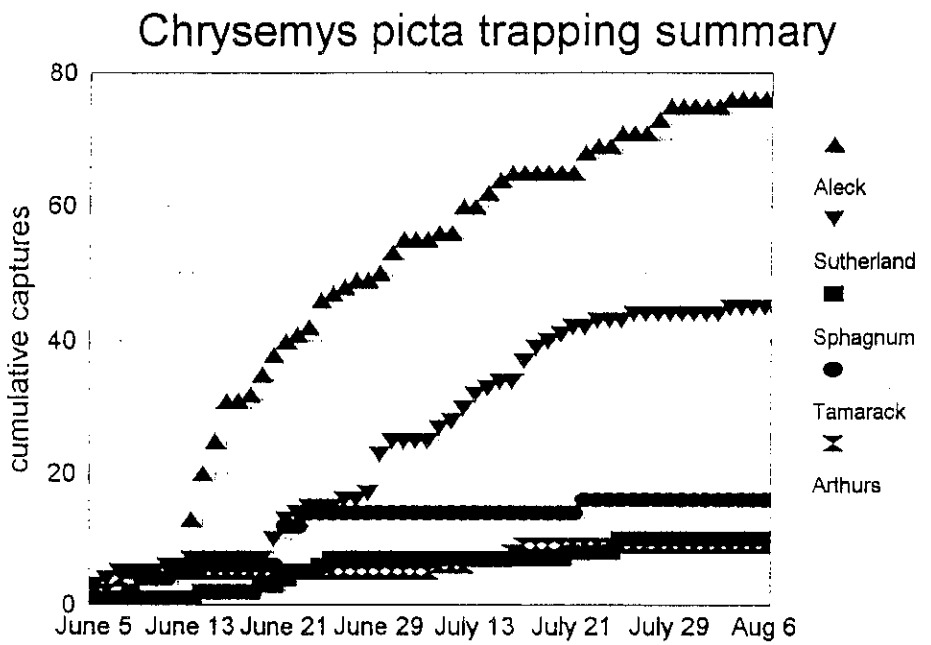

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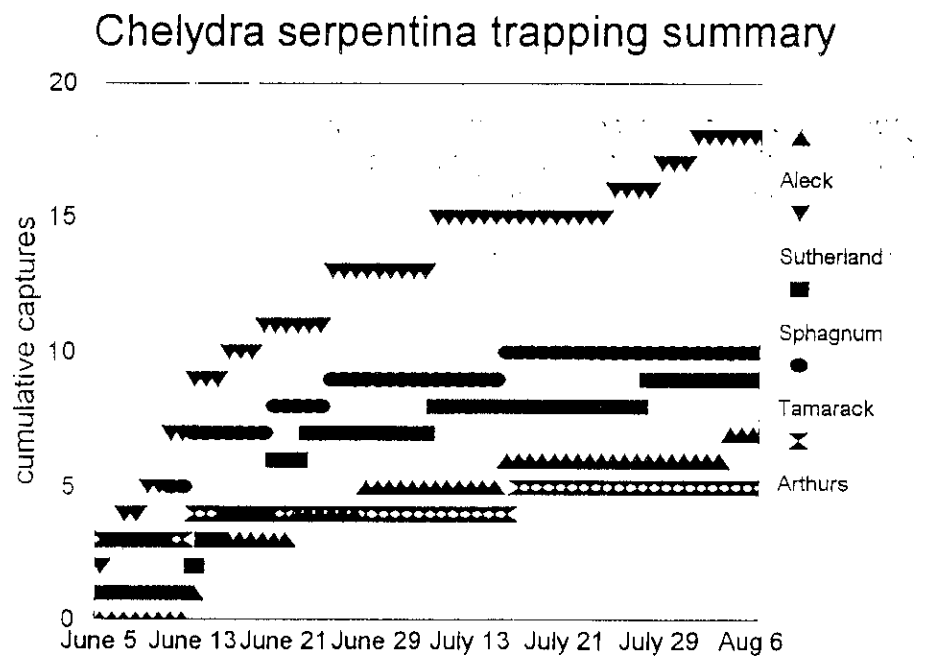

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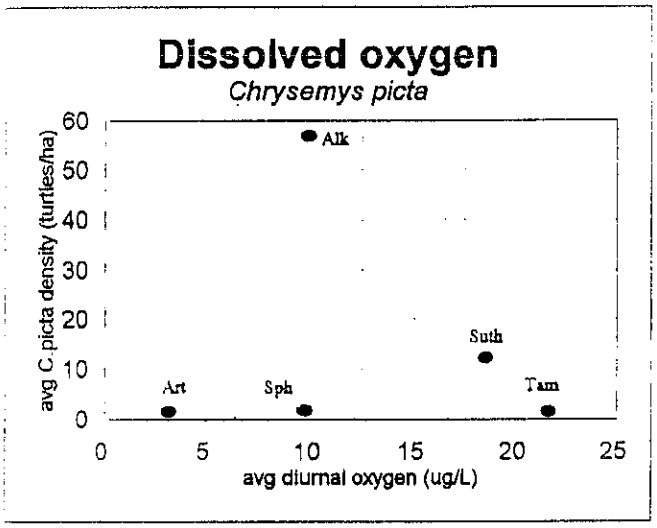

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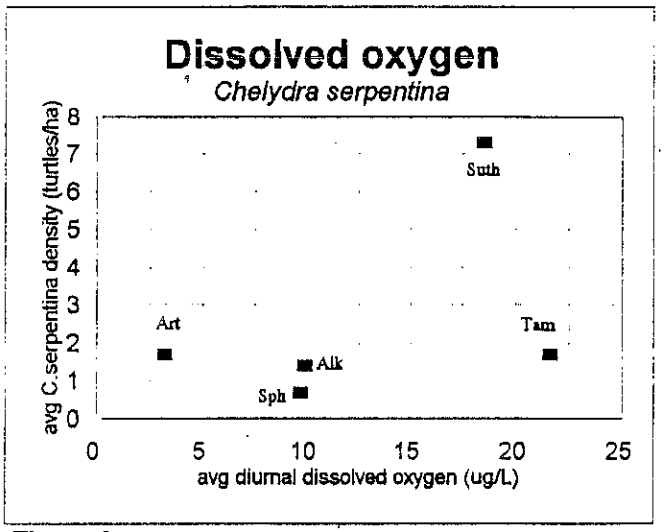

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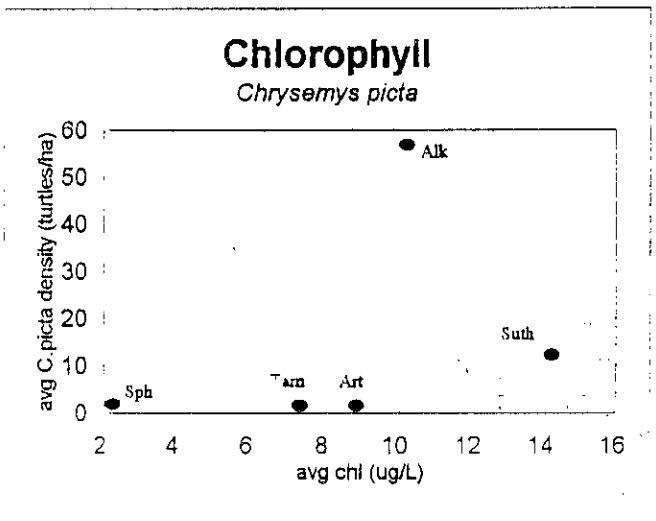

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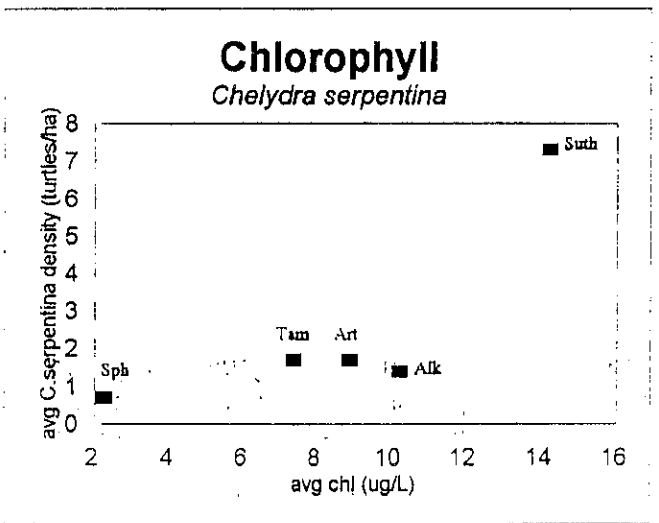

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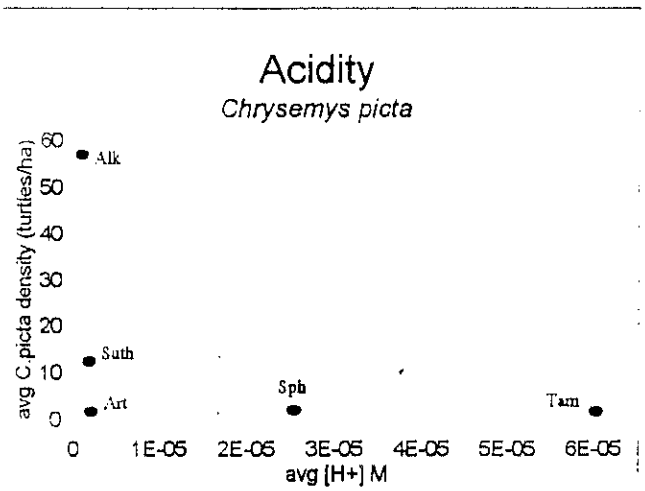

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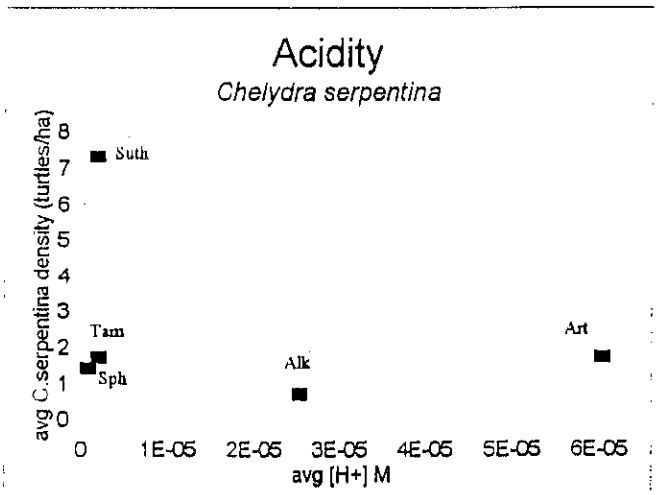

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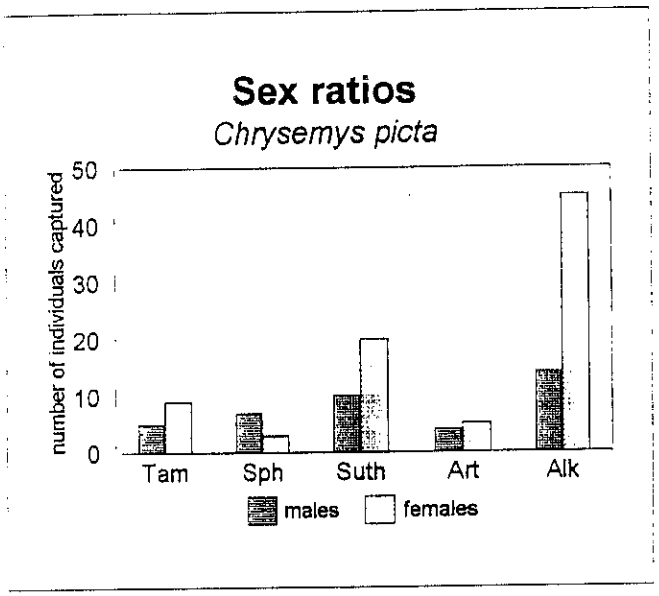
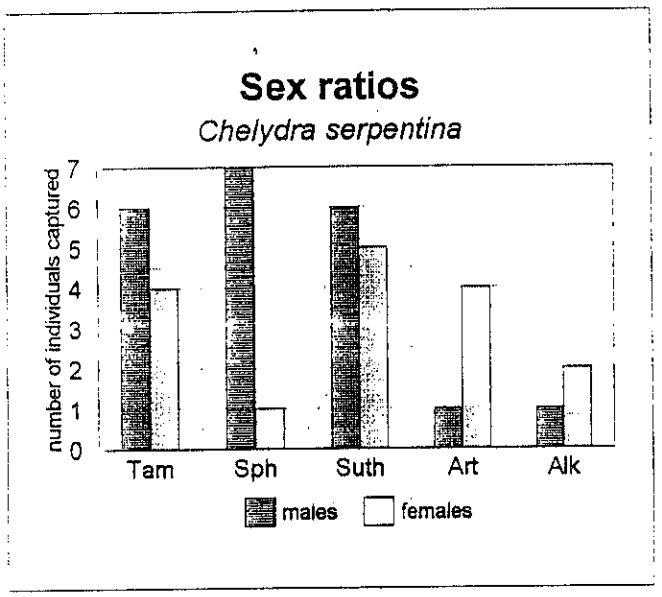


Figure7a



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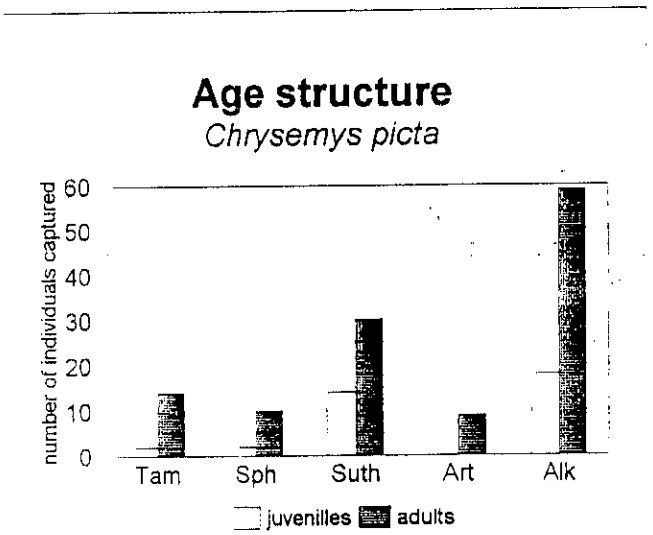

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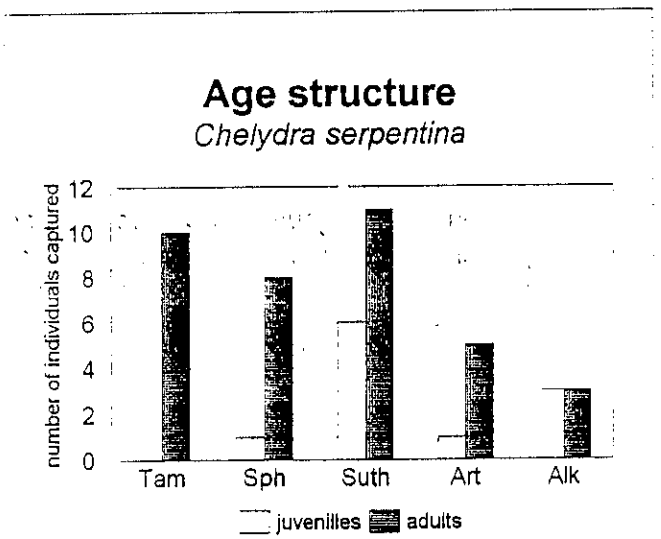

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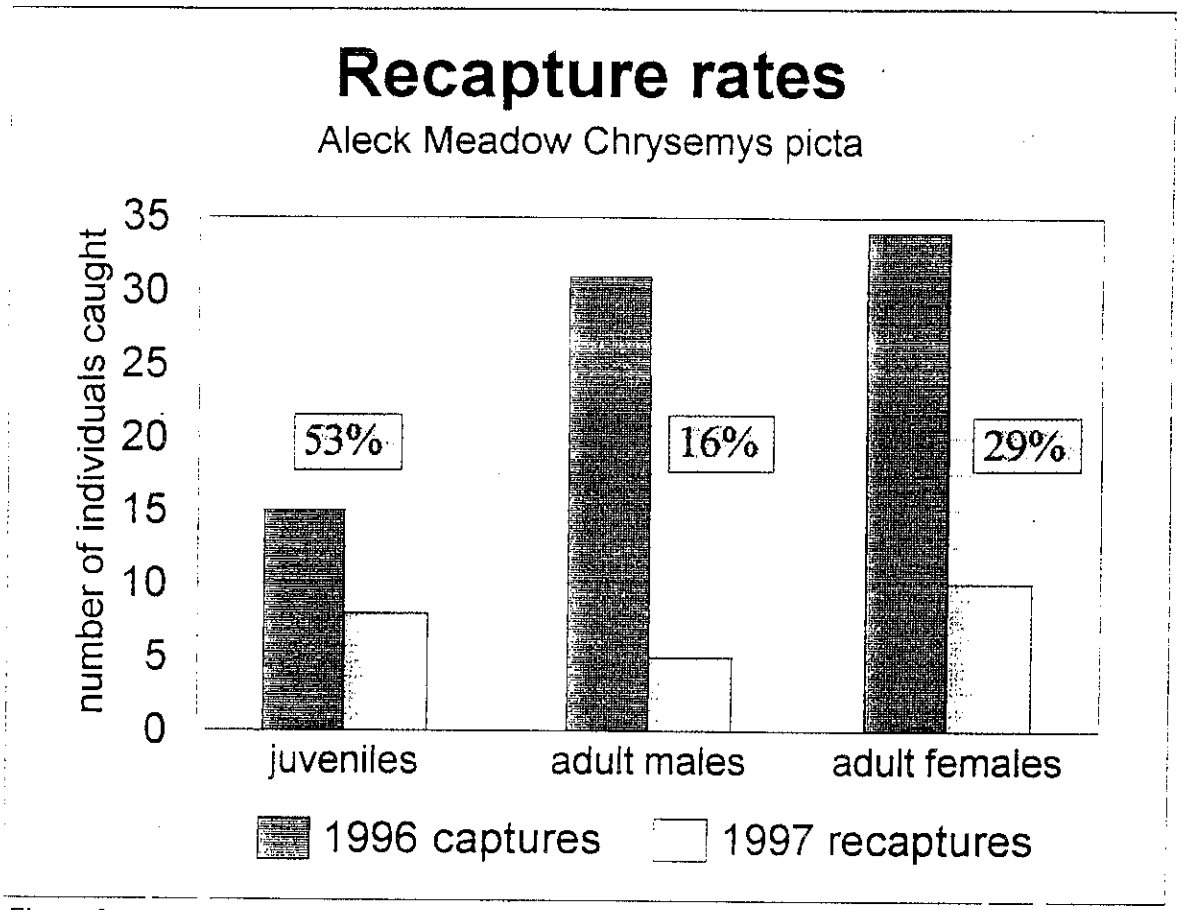

Recapture rates
Aleck Meadow Chrysemys picta
number of individuals caught
35
30
25
20
15
10
5
0
53%
16%
29%
juveniles
adult males
adult females
1996 captures
1997 recaptures

Figure 9

Trapping data summary

Chrysemys picta	Tam	Sph	Suth	Art	Alk[1]
individuals captured	16	12	44	9	77
recapture events	2	7	14	8	42
individuals recaptured	2	3	9	5	21
adult males	5	7	10	4	14
adult females	9	3	20	5	45
juveniles	2	2	14	0	18

Chelydra serpentina	Tam	Sph	Suth	Art	Alk
individuals captured	10	9	17	6	6
recapture events	13	8	14	5	10
individuals recaptured	5	3	7	3	4
adult males	6	7	6	1	1
adult females	4	1	5	4	2
juveniles	0	1	6	1	3

Table 1

"Individuals captured" refers to the number of unique turtles caught. "Recapture events" is the sum of all recapture data, while "Individuals recaptured" refers to the number of unique turtles that were recaptured.

Pond chemistry summary

	Tam	Sph	Suth	Art	Alk
elevation (m)	398	381	380	375	314
avg [H+] in M	6E-05	2.5E-05	1.5E-06	1.7E-06	5E-07
avg pH	4.3	4.7	5.9	5.8	6.3
avg chl (ug/L)	7.3	2.2	14.2	8.9	10.2
avg temperature (C)	24.9	24.9	24.6	26.3	26.8
avg am dis.oxygen (ug/L)	236.5	248.2	247.4	249	247.34
avg pm dis.oxygen (ug/L)	258.1	257.9	265.9	252.22	257.2
avg diurnal d.o. (pm-am)	21.6	9.7	18.5	3.2	9.9

Table 2

All measurements recorded over the two month study period were averaged to obtain the above values. A complete summary of dissolved oxygen measurements is given in Appendix 1. Complete chlorophyll data and inorganic chemistry measurements are given in Appendix 2.

Petersen-Lincoln Estimates

Chrysemys picta population estimates	Tam	Sph	Suth	Art	Alk
wk 1-2	0	0	54	0	185
wk 3-4	8	12	46	5	164
wk 5-6	16	14	259*	9	163
wk 7-8	0	0	51	14	0
Average estimate	12	13	50	9	171
Std. deviation	4	1	3	4	10
calculated density					
wk 1-2	0	0	13.1	0	61.7
wk 3-4	1.1	1.7	11.2	0.9	54.7
wk 5-6	2.2	2.0	0	1.6	54.3
wk 7-8	0	0	12.4	2.4	0
Average density	1.6	1.9	12.3	1.6	56.9
Std. deviation	0.5	0.1	0.8	0.6	3.4

Chelydra serpentina population estimates	Tam	Sph	Suth	Art	Alk
wk 1-2	21	3	30	12	2
wk 3-4	8	6	12	8	5
wk 5-6	14	0	17	0	6
wk 7-8	8	0	60	0	0
Average estimate	13	5	30	10	4
Std. deviation	5	2	19	2	2
calculated density					
wk 1-2	2.9	0.4	7.3	2.1	0.7
wk 3-4	1.1	0.9	2.9	1.4	1.7
wk 5-6	1.9	0	4.1	0	2.0
wk 7-8	1.1	0	14.6	0	0
Average density	1.7	0.7	7.3	1.7	1.4
Std. deviation	0.7	0.2	4.6	0.3	0.6

Table 3

The above densities are calculated by taking the turtle estimation/pond area in hectares.

Values of zero are not included in calculation of averages.

*values were not included in average or standard deviation calculation.

Correlation coefficients

	diurnal D.O.	[H+]	chl
Chrysemys picta	-0.12	-0.45	0.35
Chrysemys picta w/o Alk	0.41	-0.49	0.8
Chelydra serpentina	0.46	-0.37	0.79

Table 4

Aleck Meadow Recapture Estimates
Chrysemys picta

	Pet-Lin population estimate
1996 mark/recap	203
1997 mark/recap	171
1996 mark/1997 recap	291

Table 5

Recaptured individuals

Chrysemys picta	**Tam**	**Sph**	**Suth**	**Art**	**Alk**
3 or more times	0	0	1	1	4
1-2 times	2	3	8	4	17
never recaptured	18	9	35	4	56

Chelydra serpentina	**Tam**	**Sph**	**Suth**	**Art**	**Alk**
3 or more times	2	0	2	1	0
1-2 times	3	3	5	2	4
never recaptured	7	6	10	3	2

Table 6

Deformed turtles

	Tam	**Sph**	**Suth**	**Art**	**Alk**
avg [H+]	6E-05	2.5E-05	1.5E-06	1.7E-06	5E-07
Chrysemys picta					
total captured	16	12	44	9	77
number deformed	2	2	3	0	1
percent deformed	12.5%	16.5%	6.8%	0.0%	1.3%
Chelydra serpentina					
total captured	10	9	17	6	6
number deformed	1	1	0	2	0
percent deformed	10.0%	11.1%	0.0%	33.3%	0.0%

Table 7

Appendix 1
Dissolved Oxygen data

All dissolved oxygen data collected during the study period are presented in the following tables. All five ponds were found to be consistently supersaturated with oxygen for the recorded temperatures. Graphs of dissolved oxygen measurements over time are shown in Figures 1-5.

Tamarack

	June 21	June 30	July 3	July 11	July 16	July 21	July 31
am ug/L	254.5	223.8	217.2	249.0	232.6	220.0	258.5
pm ug/L	262.1	261.2	259.3	250.1	252.4	257.7	264.0
am temp	23.0	23.0	23.0	23.3	27.1	27.1	22.4
pm temp	27.2	27.2	27.2	27.2	30.4	30.4	27.3
am sat	224.3	224.3	224.3	222.4	199.9	199.9	228.1
pm sat	199.4	199.4	199.4	199.4	182.7	182.7	198.8
%O2 am	113.5	99.8	96.8	111.9	116.4	110.0	113.3
%O2 pm	131.5	131.0	130.1	125.5	138.2	141.1	132.8

Sphagnum

	June 21	June 30	July 3	July 11	July 16	July 21	July 31
am ug/L	259.9	256.9	232.9	240.6	253.0	227.0	267.0
pm ug/L	257.2	238.1	238.6	246.6	248.9	247.8	328.2
am temp	23.0	23.0	23.0	23.8	27.0	27.0	24.1
pm temp	26.0	26.0	26.0	26.0	28.2	28.2	26.3
am sat	224.3	224.3	224.3	219.3	200.5	200.5	217.4
pm sat	206.1	206.1	206.1	206.1	193.9	193.9	204.4
%O2 am	115.9	114.6	103.9	109.7	126.2	113.3	122.8
%O2 pm	124.8	115.5	115.8	119.6	128.3	127.8	160.5

Sutherland

	June 21	June 30	July 3	July 11	July 16	July 21	July 31
am ug/L	242.5	227.6	228.5	277.8	252.1	235.5	267.7
pm ug/L	248.8	270.4	253.8	294.2	262.2	257.7	274.1
am temp	23.0	23.0	23.0	23.9	27.8	27.8	22.9
pm temp	25.7	25.7	25.7	25.7	29.8	29.8	25.6
am sat	224.3	224.3	224.3	218.7	196.1	196.1	224.9
pm sat	207.9	207.9	207.9	207.9	185.6	185.6	208.4
%O2 am	108.1	101.5	101.9	127.1	128.6	120.1	119.0
%O2 pm	119.7	130.1	122.1	141.6	141.3	138.8	131.5

Arthurs

	June 21	June 30	July 3	July 11	July 16	July 21	July 31
am ug/L		238.4	253.6	255.8	255.8	236.0	254.4
pm ug/L		255.5	259.0	244.1	148.4	244.5	258.1
am temp	23.0	23.0	23.0	23.3	27.8	27.8	23.7
pm temp		24.8	24.8	24.8	27.7	27.7	24.8
am sat	224.3	224.3	224.3	222.4	196.1	196.1	219.9
pm sat	421.5	213.2	213.2	213.2	196.6	196.6	213.2
%O2 am		106.3	113.1	115.0	130.5	120.4	115.7
%O2 pm		119.8	121.5	114.5	75.5	124.4	121.1

Aleck

	June 21	June 30	July 3	July 11	July 16	July 21	July 31
am ug/L	263.9	240.9	238.8	255.7	263.6	226.1	242.3
pm ug/L	301.3	251.5	248.8	263.1	238.7	244.6	252.3
am temp	23.0	23.0	23.0	24.4	28.3	28.3	22.9
pm temp	26.4	26.4	26.4	26.4	30.8	30.8	26.2
am sat	224.3	224.3	224.3	215.6	193.4	193.4	224.9
pm sat	203.8	203.8	203.8	203.8	180.7	180.7	205.0
%O2 am	117.7	107.4	106.5	118.6	136.3	116.9	107.7
%O2 pm	147.8	123.4	122.0	129.1	132.1	135.4	123.1

Appendix 2
Chlorophyll data and inorganic chemistry measurements

Chlorophyll data

Four chlorophyll samples were averaged to obtain the figures discussed in this paper. Data are shown below. In most cases, chlorophyll concentration increases towards the end of the sampling period. This could either be a true reflection of seasonal changes, or a perfection of the method with practice. Because chlorophyll is degraded by sunlight, different exposures could account for the variations in measurements. Sampling techniques did become quicker later in the season; samples received less exposure and were stored in a freezer more quickly after being filtered. The average values presented here may be taken as minimum chlorophyll values due to sampling error.

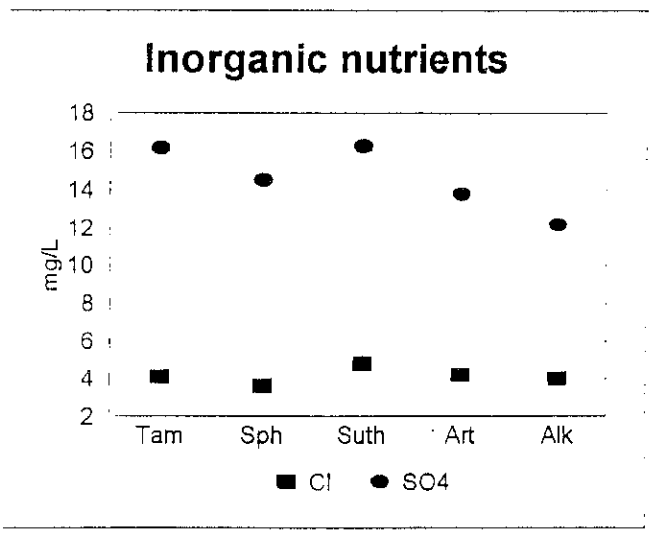
	Chlorophyll ug/L				
	06/19/97	**06/20/97**	**06/30/97**	**07/03/97**	**average**
Tam	1.5	2.3	7.1	18.5	7.34
Sph	1.8	0.7	1.6	4.9	2.25
Suth	5.6	7.8	19.6	23.9	14.21
Art	9.7	0*	5.8	11.1	8.86
Alk	4.3	1.8	19.1	15.7	10.23

*sample was lost, not included in calculation of the average

Inorganic chemistry measurements

Water samples from each pond were analyzed for inorganic nitrate (NO4), sulfate (SO4), and chlorine (Cl). Results are presented below. Nitrate concentrations were not detectable below 0.2mg/L. Because NO4 is a nutrient used by phytoplankton, it is likely any NO4 is utilized as soon as it becomes available. Measurements do show a general decresing trend with elevation. Samples were taken July 21, 1997.

	Inorganic chemicals (mg/L)			
	NO4	**SO4**	**Cl**	**elevation**
Tam	0	16.2	4.1	398m
Sph	0	14.5	3.6	381m
Suth	0	16.3	4.8	380m
Art	0	13.8	4.2	375m
Alk	0	12.2	4	314m
Std Dev	0	0.4	0.1	



Appendix 3
pH measurements

Measurements of pH were taken at three locations at each pond (usually at tra occasions during the study period. Daily averages are plotted over time in the chart be vary considerably over the measured days.

	pH measurements					
	07/10/97	**07/13/97**	**07/25/97**	**07/30/97**	**average**	
Tam	4.1	3.8	4.3	4.6	4.3	Tam
	4.4	4.1	4.2	4.4		Sph
	4.3	4.1	4.5	4.4		Suth
daily avg	4.3	4.0	4.3	4.5		Art
						Alk
Sph	4.4	4.6	5.0	4.9	4.7	
	4.3	4.3	4.4	5.2		
	4.6	4.6	4.7	4.7		
daily avg	4.4	4.5	4.7	5.0		
Suth	5.6	5.8	6.2	6.2	5.9	
	4.6	5.6	6.2	6.3		
	5.9	6.2	6.3	6.6		
daily avg	5.4	5.9	6.2	6.4		
Art	5.8	6.3	5.7	5.6	5.8	
	5.8	6.1	5.9	5.8		
	5.9	5.8	5.8	5.9		
daily avg	5.8	6.0	5.8	5.7		
Alk	6.1	5.8	6.6	6.6	6.3	
	6.1	6.4	6.4	6.3		
	6.1	6.3	6.5	6.3		
daily avg	6.1	6.2	6.5	6.4