The Effects of pH and Lakewater Calcium on Growth of the Yellow Perch (*Perca flavescens*) UNDERC, Northern Wisconsin/Michigan

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Synopsis

Key words: pH, calcium hardness, alkalinity, conductivity, condition factor, age class, yellow perch

In five lakes that showed natural differences in pH and calcium hardness, yellow perch (*Perca flavescens*) were trapped on a daily basis over the time period 10 June through 27 July 1987 at the University of Notre Dame Environmental Research Center in northern Wisconsin. The average length of a year class and the average condition factor were measured for each lake's perch population as indicative of its overall growth rate. These values were compared among one another in terms of both the lakewater pH and the calcium levels. Both the average length and the average condition factor were found to increase proportionally with pH but calcium had no apparent effect. However, inconsistencies in the presence of certain year classes were found in lakes with calcium levels at or below 10 mg l^{-1} but demonstrated no obvious relationship to pH.

Introduction

For as long as it has existed, the science of ecology has attempted to attain an understanding of the delicate balances existing between organisms and their environments. Freshwater fishery biology, both in theory and in practice, looks specifically at the place of fish in the ecosystem; it examines the factors causing changes in the behavior and biology of fish as well as the ways they have to deal with these changes. These kinds of studies are extremely important considering the significant roles played by fish as both consumers and as sources of staple food - not only for other fish, birds, mammals, and reptiles, but also for man (Gerking 1978).

Growth analysis is an important parameter often used in systems ecology. Fish growth in particular is known to be very labile; because fish are poikilothermic and live permanently immersed, the conditions of the water affect them greatly (Weatherley 1972). In addition, fish by nature grow indeterminately; that is, their growth patterns under natural conditions often differ even within a species. This is quite rare for bird and mammal populations, whose growth patterns are usually more constant (Weatherley and Gill 1987). Finally, using fish growth rates in ecological study is valuable because "whereas most higher vertebrates have maximal sizes which are not surpassed even during abnormally long lifetimes, fish appear to continue growing (so long as food supplies are not limiting) for as long as they live" (Weatherley and Gill 1987). Thus growth analyses may be used to study whole populations regardless of the age groups comprising the populations.

Two major extrinsic factors have long been known to affect the growth of fish: the physical factor of temperature and the biotic/ecologic one of competition for food (Weatherley and Rogers 1978). Another such agent which has received attention in the recent literature is pH. Many studies relating environmental acidity and alkalinity to general fish physiology (Bhaskar and Govindappa 1986), biochemical activities (Matsuura and Arai 1986), tissue mineral content (Sadler and Lyman 1986; Bendell-Young and Harvey 1986), and species richness (Rage and Wiener 1986) are examples. These studies were likely prompted by the exploitation of fish stocks which has occurred over the past decades and the desire to discover whether and how fish habitats - especially those in fresh water - have been reduced as a result of environmental acidification (Gerking 1978).

Unfortunately, the data attributing growth patterns in freshwater fish populations to experimental or natural variations in pH has been inconclusive thus far. Reduced growth is frequently observed under conditions of low pH (Fromm 1980). However, a study done on the natural acidification of freshwater lakes in Ontario produced complicated results; the yellow perch of age groups 1-3 actually increased their growth rates while those of age groups 4-9 exhibited reduced growth (Ryan and Harvey 1980). It was postulated that the younger perch grew faster in acidified lakes due to a decrease in population density caused by the acidification; however, this was not proven.

The fact that reductions in the growth rates of fish have not been consistently linked to decreases in pH casts some question as to whether these two variables are directly related. It is possible that the pH may be interacting with particular substances in the water and that these interactions affect the fish (Sadler and Lyman 1986). Alternatively, a low pH may somehow cause a decrease in food supply, causing an increase in competition for that supply and therefore stunted growth (Fromm 1980). One particular experiment lends indirect support to the first hypothesis. Under conditions constant food intake conditions, yearling brown trout were more tolerant of acidic water when small amounts of calcium were present than when the water was virtually calcium-free (Sadler and Lyman 1986). This suggests the presence of some sort of relationship - direct or indirect - between pH and mineral content as determinants of fish growth rates.

If low pH has an effect upon fish growth, there are at least four possible methods by which it may act. These are: 1) interference with normal reproduction; 2) precipitation of gill mucus and gill membranes; 3) interference with ionic regulation; and 4) interference with the transport of respiratory gases to tissues (Fromm 1980). There has been some evidence to support the idea of interference with normal reproduction; prior to extinction of a species due to extremely low pH, most of the females did not release ova. This failure to spawn was synchronous with an inability to maintain normal calcium levels in the serum (Beamish 1976). Once again, a relationship between pH and calcium is apparent. The effects of acidity on ionic balance and respiration, in turn, are presumed to be this: Hydrogen ions flow across the gills into the blood and decrease the blood pH. This may cause acidemia because of a subsequent decrease in excretion of metabolically-produced H^+ and carbon dioxide into the acid water medium. The capacity of the fish's buffer system exceeded, the blood pH is thus lowered and the oxygen-carrying capacity of the hemoglobin is diminished (Fromm 1980).

Five lakes were used in my study of the effects of lakewater pH and calcium content on fish growth. Their chemical differences are completely natural. The degree of calcium- and magnesium-dependent alkalinity in the waters varies with the ions coming into the lakes from their watersheds (rainwater contributes little to the lakes ionic balance under normal circumstances). These ions are mobile in the soil to varying degrees. Calcium and magnesium, the predominant ions, are base cations and therefore quite soluble in water. The higher their concentrations in the watershed of a lake, the higher the alkalinity of the lake. On the north end of the UNDERC property, the underlying rocks contain very high calcium and magnesium levels, making the lakes in this area (e.g. Morris) very alkaline. By contrast, the center and southeast corner of the property both contain rocks which are poorer in base cations and as a result the lakes in these areas are somewhat more acidic (Carpenter 1987). Specific conductance, in addition to alkalinity, is also positively related to ion content in water (Carpenter 1987). Both of these values are utilised in my study.

The yellow perch (*Perca flavescens*) was chosen as the experimental organism in my study because its growth is already stunted in some of the lakes. Informal observations had indicated that the stunting was especially prevalent in the more acidic lakes on the property (Goetz 1987). In this study, quantitative comparisons are made among the growth patterns of yellow perch populations *(Perca flavescens)* in differing lake environments. To make such comparisons it is necessary to choose specific criteria which reflect differences in growth patterns among groups of fish rather than among individuals.

The first of these criteria that I have chosen to compare fish with is the average length of the fish of a particular year class. Length rather than weight estimates growth more precisely because weight often fluctuates significantly, and depends on factors such as whether the fish has eaten recently. The fourth year class was chosen because it was the youngest caught from all five of the lakes in the study. Secondly, a variable called condition factor is a useful indicator of fish growth. The condition factor is often helpful in making comparisons among conspecific populations of fish living under different conditions of food, density, climate, etc. (Weatherley and Gill 1987). Mathematically, the condition factor of an individual is equal to:

$$w/l^3$$

where w=weight of the fish in grams and l=length of the fish in centimeters (Goetz 1987). This equation is applicable to any material body whose linear proportions remain constant with increasing size (Weatherley and Gill 1987). The condition factor therefore remains constant regardless of how large the fish becomes. Despite its advantages, some have pointed out that the condition factor may vary due to its dependence on the fish's weight (Weatherley 1972). It is, nevertheless, commonly and effectively used to compare growth among populations, especially because of the convenient condensation of the length-weight data.

The purpose of this study was to verify and quantify the correlation between reduced growth of yellow perch and acidic (low pH) and/or soft (low calcium) lakewater environments, basing "growth" on lengths attained by a certain age as well as weights attained by a certain length.

Materials and Methods

Chemicals, Reagents, and Equipment. 96% sulfuric acid was purchased from Mallinckrodt. B-D IM-1 Precision Glide needles were used in bloodletting; Eppendorf micropipetmen were used for the Gran alkalinity procedure. All other sources are identified within the text of this section. Distilled water was used for all solutions.

Lakes. Bergner, Long, Morris, and Raspberry Lakes and Hummingbird Bog are all located within the University of Notre Dame Environmental Research Center (UNDERC), a 2833-hectare northern temperate lake region split by the Michigan-Wisconsin state line whose center is at 48 13' North by 89 32' East (Greene ND).

Fish. Yellow perch (*Perca flavescens*), easily identified by characteristic morphology: gold body with brown dorsal stripes, terminal mouth position, etc.

FIELD PROCEDURES

Eight lakes were chosen for preliminary examination based on previously-obtained chemical data (Greene) and on recent reports indicating their inhabitation by yellow perch (Goetz 1987; Greene; Bremigan 1987).

Water Chemistry Analysis (from Carpenter 1987). All sampling was done at the upper metalimnionic/lower epilimnionic layer, whose location was standardized as the depth immediately above the beginning of the thermocline in each lake. Temperature probes (Yellow Springs International) were used to determine this depth. Over five consecutive days conductivity readings (Yellow Springs International specific conductance probe) and an approximately one-liter water sample were each taken once for the eight lakes, using a 3.2-liter van Dorn sampler (Wildco). The sampling time was standardized as 10:00 A.M. to minimize circadian fluctuations from in the data. The lake water was immediately taken to the lab and magnetically stirred with a Sybron Thermolyne magnetic stirrer for ten minutes to allow equilibration with atmospheric carbon dioxide before a pH reading (Orion Research Digital Ionizer/501 pH meter) was taken and the Gran alkalinity procedure was run in duplicate according to Zimmerman and Harvey (1979). Actual alkalinities were calculated on the Dyna PC/XT computer from average data using a program specifically designed for this purpose by Dr. Stephen R. Carpenter, Department of Biological Sciences, University of Notre Dame.

Water samples from each of the eight lakes were frozen in 100 ml glass jars and transported to Notre Dame for specific calcium analysis to be done the following autumn (see "Laboratory Procedures - Notre Dame").

Determination of lakes to be used for study (from Goetz 1987). Five lakes were selected for further experimentation on the basis of extremes in pH as well as the relative calcium levels suggested by the alkalinity and specific conductance data.[1]

Trapping of Fish (from Goetz 1987). South Dakota trap nets (12' long, 4' x 50' main leader and 4' x 25' side leaders of 1" mesh, with five 36" galvanized hoops and two 4' x 4' aluminum frames; Sterling Marine Products) were set in random, high-macrophyte areas in each of the five selected lakes. In most cases two nets occupied one lake simultaneously, but this number ranged at times from one to four.

[1] A high value for either alkalinity or specific conductance was interpreted to represent a correspondingly high calcium concentration.

In Morris, Bergner, Raspberry, and Long Lakes, the full length of the front leader of the net was utilized and each side leader was placed at an angle of approximately 45 degrees to the shore. The top of the square frame was one foot or less from the surface of the water. In Hummingbird Bog, only half the length of the front leader was used due to the sharp drop of the shore; the side leaders were extended almost parallel to the shore to compensate. The top of the frame reached two to three feet below the surface of the water in the bog. In all cases the nets were cleared and reset daily for a period of seven days.

The fyke nets proved unsuccessful in Bergner. An occasional tiny yellow perch did enter the net but in all but one case was rapidly eaten by a bass. Minnow traps (17 1/2" long, 9" high, of galvanized wire and steel and 1/4" square mesh; also from Sterling Marine Products) were therefore used to collect the major portion of the fish from this lake. Whether baited with sliced white bread or left empty, they produced a far better yield than did the fyke nets.

Data Collection - Field (from Goetz 1987). All species excluding *Perca flavescens* were thrown back immediately after clearance of each net. The yellow perch were taken to shore and maintained in aerated water until data could be taken. Total lengths were obtained using a metric ruler built into a wooden board. Each fish was then weighed on either a 100g or 500g Pesola Spring clip scale (Forestry Suppliers, Inc.) depending on its relative size. Approximately four to ten scales were next removed with Dumont Type 5 electron microscopy forceps from immediately behind the head just below the lateral line, on the left side of the body. The scales were placed between folds of glassine paper (Fisher Scientific Co.) and the length and weight data recorded on the front of small coin envelopes. All perch were marked with a paper punch hole in the tail fin before being released so that data was never taken from the same fish upon subsequent re-trappings.

Some perch were selected at random each day to be taken to the lab to contribute tissue samples for calcium analysis. These were maintained in aerated water until further treatment.

The field work on all lakes was completed between 10 June and 26 July 1987.

LABORATORY PROCEDURES - UNDERC

Data Collection - Laboratory (from Goetz 1987). The fish of the aforementioned subsample were placed individually in an approximately 1:1000 dilution of the anaesthetic 2-phenoxyethanol (J.T. Baker Co.). Immediately after movement began to wane each was removed and blood drawn from the caudal vein on the right side of its body into a 1cc Sigma syringe coated with a 5.6 mg ml^{-1} solution of heparin (from porcine intestinal mucosa, Sigma Chemical Co.) in isotonic sodium chloride (Sigma Chemical Co.). Up to 1 ml of blood was taken from each fish, depending on how much its size would allow. The fish was then killed by a blow to the head with a large rock. Approximately two cubic inches of skinless flesh was removed from just beneath the first dorsal fin, as was a section of the vertebral column from the corresponding area. The whole brain was also removed. All samples except blood were placed in 4 dram insect vials or 20 ml glass scintillation vials and frozen. Each blood sample was refrigerated in a 1.5 ml micro tube (Bio-Rad) until further processing could be done.

Isolation of Plasma. The blood sample tubes were securely placed in larger plastic tubes and centrifuged in the Damon/IEC Division HN-5 centrifuge at "full speed" (approximately 3500 rpm) for fifteen minutes. The resulting supernatants were transferred to new micro tubes and frozen.

LABORATORY PROCEDURES - NOTRE DAME

Aging. The annulus-counting method was used to determine age class for each fish (Lagler 1952). Fish scales were placed on a glass slide with a drop of water and a cover slip. At least four scales from each animal were examined under high power on the Bausch and Lomb microprojector before its age class was recorded.

Water Calcium Determinations. Analysis of calcium present as calcium carbonate in the five lakes under study was done on the frozen water samples. This followed directly the CalVer II titration method in Hach Kit model DR-EL/2 (Anon. 1974). Distilled water was run as a blank. Glassware was cleaned by rinsing four times with tap water, one time with hydrochoric acid (Fisher Scientific Co.) made to 5%, then three times with distilled water. The glass bin used for the acid wash was cleaned with Isoclean Concentrate All Purpose Laboratory Detergent (Isolab, Inc.) before use.

Tissue Calcium Determinations. Blood, brain, bone, and muscle will be digested, liquefied, and subjected to atomic absorption analysis for calcium content. This part of the study is not yet finished at this writing and will take several additional months to complete.

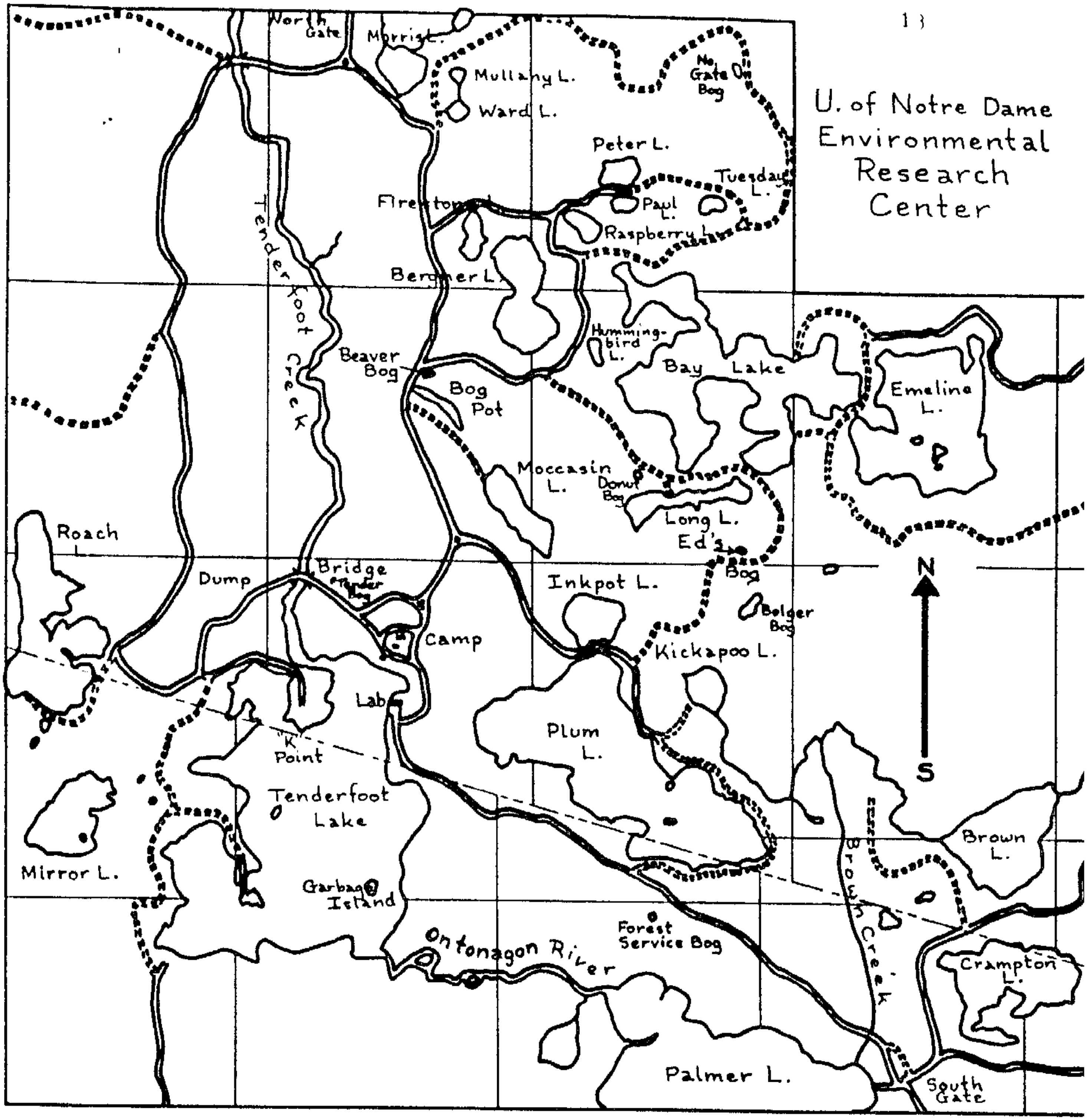
Results

A map of the UNDERC property is shown in Figure 1.

Lakewater chemistry. Table 1 compiles all the water chemistry measurements obtained before the five lakes comprising the study were chosen. The data were compared to those in the official UNDERC property fact book (Greene) and found to correlate in the following manner.

While the acidities of six of the lakes were observed to be roughly close to the corresponding values in the handbook, both Crampton and Morris gave significantly higher pH readings in this study than those indicated by the handbook (Figure 2). The high pH of Morris Lake obtained in my study was confirmed by other students of the 1987 UNDERC class, who determined it to be 7.44. The alkalinity units I used (ueq l^{-1}) were different than those used in the guide book (mg l^{-1}), making comparisons inconvenient. However, conductivity trends (measured in umho cm^{-1}) were very similar, as shown in Figure 3.

The methodology we used to rule out three of the eight lakes from experimental consideration was based on informal observations made during the chemical data collections. Firestone Lake was deemed unsuitable for the fish study mainly because of its lack of substance; it resembled a marsh far more than a lake and major fish habitation was not evident. Crampton Lake had originally been of interest because of the low pH value (4.0) assigned it in the previous literature (Greene), but this was disproven; fortunately, two other lakes had sufficiently high acidities for the purposes of this experiment (Bergner and Hummingbird). Kickapoo Lake was found to be chemically quite similar to Morris Lake in acidity and alkalinity. However, because of the apparently larger numbers of perch in



Legend

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Unimproved dirt road	=======
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SCALE

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1 mile

Table 1 Lakewater Chemistry

Lake	pH	Alkalinity ($ueq\ l^{-1}$)	Conductivity ($umho\ cm^{-1}$)	Ca^{2+} Hardness ($mg\ l^{-1}$)
Morris	7.64	494.22	80.5	41.7
Long	6.21	6.21	18.5	10.0
Raspberry	6.09	14.38	12	*5.0
Bergner	5.52	5.58	12	*5.0
Hummingbird	5.01	4.80	19.5	*8.3

* Less than or equal to this value.

Table 2 Parameters of Comparison

	pH	calcium ($mg\ l^{-1}$)	Avg length (cm) of 4-yr-olds	Avg condition factor (K)
Morris	7.64	41.7	19.2	0.0108091
Long	6.21	10.0	16.1	0.0097572
Raspberry	6.09	5.0	15.1	0.0071084
Bergner	5.52	5.0	14.2	0.0075004
Hummingbird	5.01	8.3	13.8	0.0069581

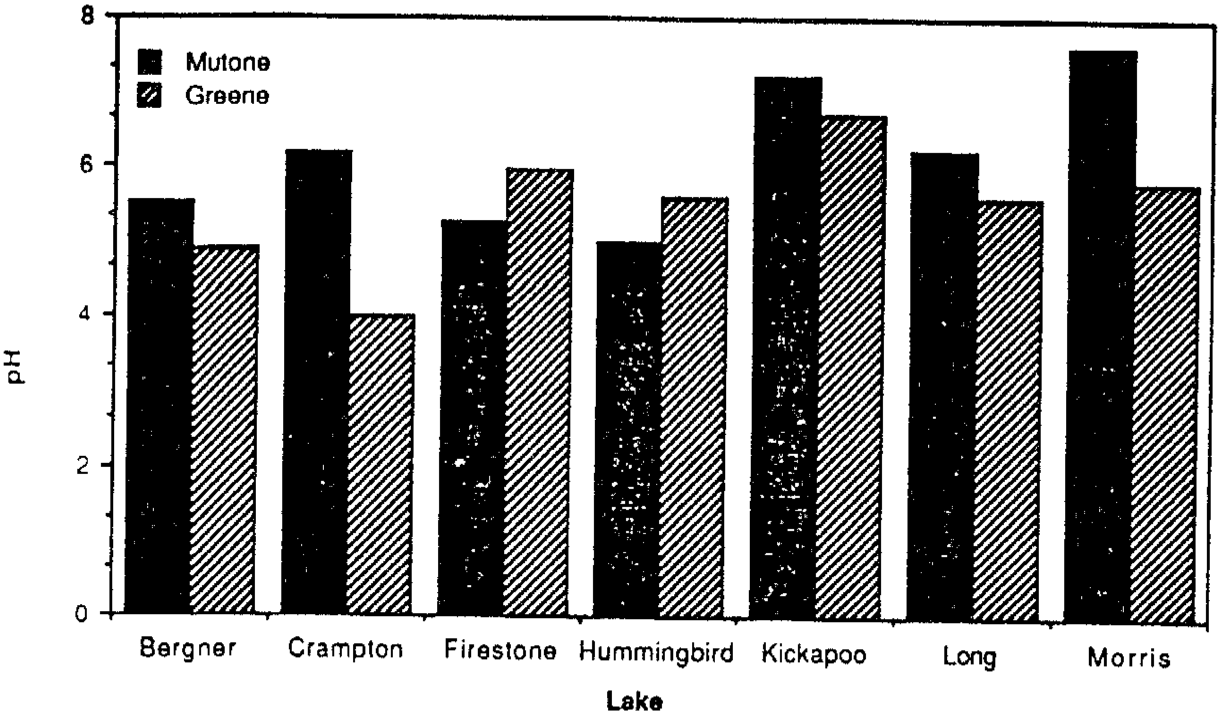


Fig.2 A comparison of the pH data obtained with previously published results. Significantly higher pH values were observed in this study in Crampton and Morris Lakes than those indicated in the UNDERC guide.

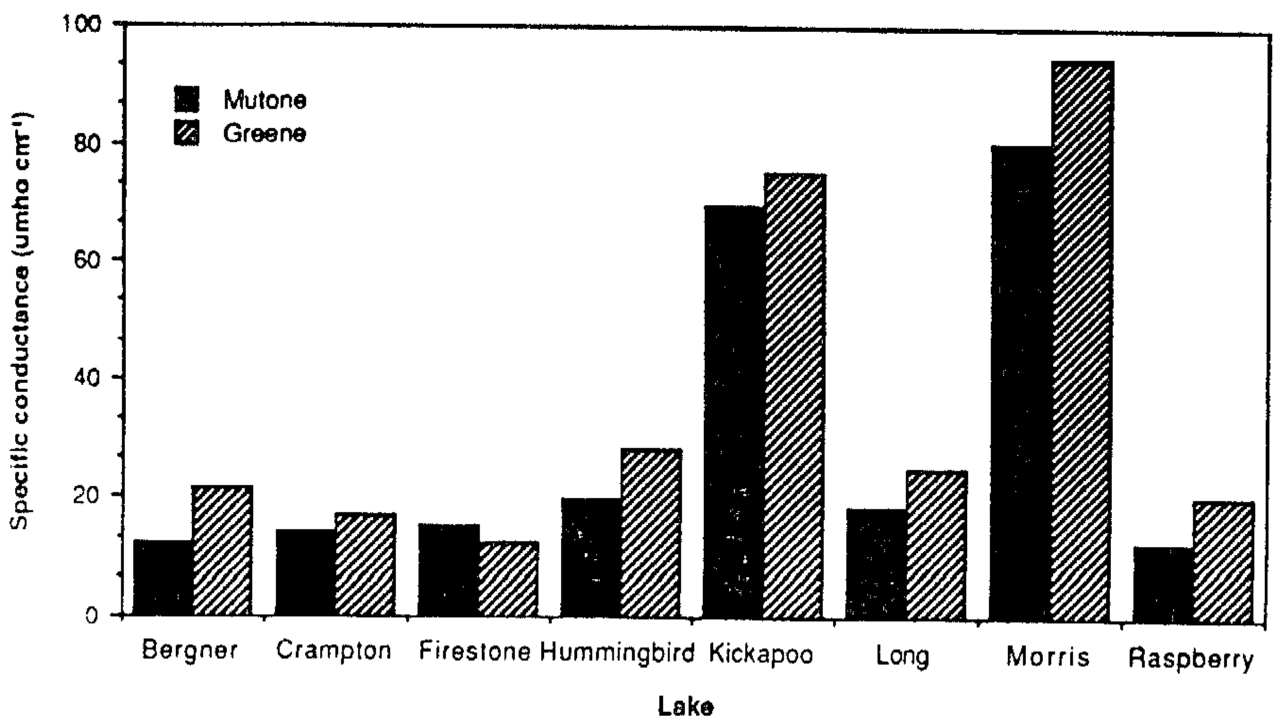


Fig.3 A comparison of conductivities obtained in this study to those previously published by Greene for the same lakes. A relatively good consistency is observed.

Morris than in Kickapoo as well as the existing political situation regarding some of the lakes on the property, we chose Morris Lake to be our representative high pH/high calcium "control" lake. The five lakes finally chosen - Morris, Long, Raspberry, Hummingbird, and Bergner - demonstrated appreciable differences in both pH and calcium content (see again Table 1).

Validity of the use of alkalinity and conductivity to measure calcium levels in the lakes. Because I knew that straightforward analysis for calcium content in the lakewater could not be done until the fall (the necessary equipment was not available), I measured alkalinity and specific conductance in order to get relative ideas of calcium levels in the lakes at UNDERC while I was there. Figures 4 and 5 illustrate the relationships found between these two indirect parameters and the actual calcium levels as measured later by the Hach kits. The graphs indicate that the measurements of alkalinity and conductivity correlated well with the actual calcium levels in these particular lakes. Note that the calcium values as measured by the Hach method are accurate only to the nearest 5 mg l^{-1}; in fact Raspberry and Bergner (and possibly Hummingbird) may have less than 5 mg l^{-1} in calcium content. This inaccuracy resulted because the titration was done in units no smaller than 50 ul and some of these lakes are evidently extremely soft. Future work with the fish tissues will require a more accurate determination of the lakewater calcium.

Whereas the water calcium values for all of the lakes except Morris were concentrated around a relatively low range, Table 1 shows an even distribution of pH among the five lakes. As expected, the bog was the most acidic. Morris Lake was the most alkaline; it was in fact the only lake in this study whose pH fell into the range (6.5 - 8.5) which normally allows

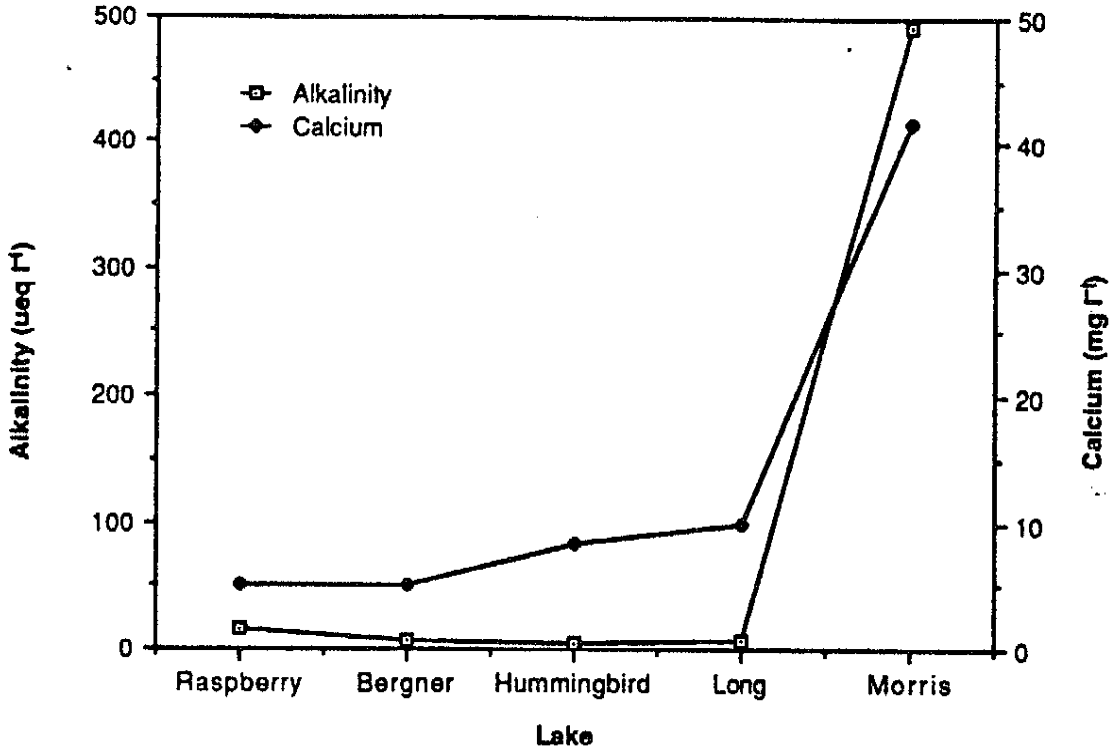


Fig. 4 Gran alkalinity of the lakewater as an indicator of calcium content.

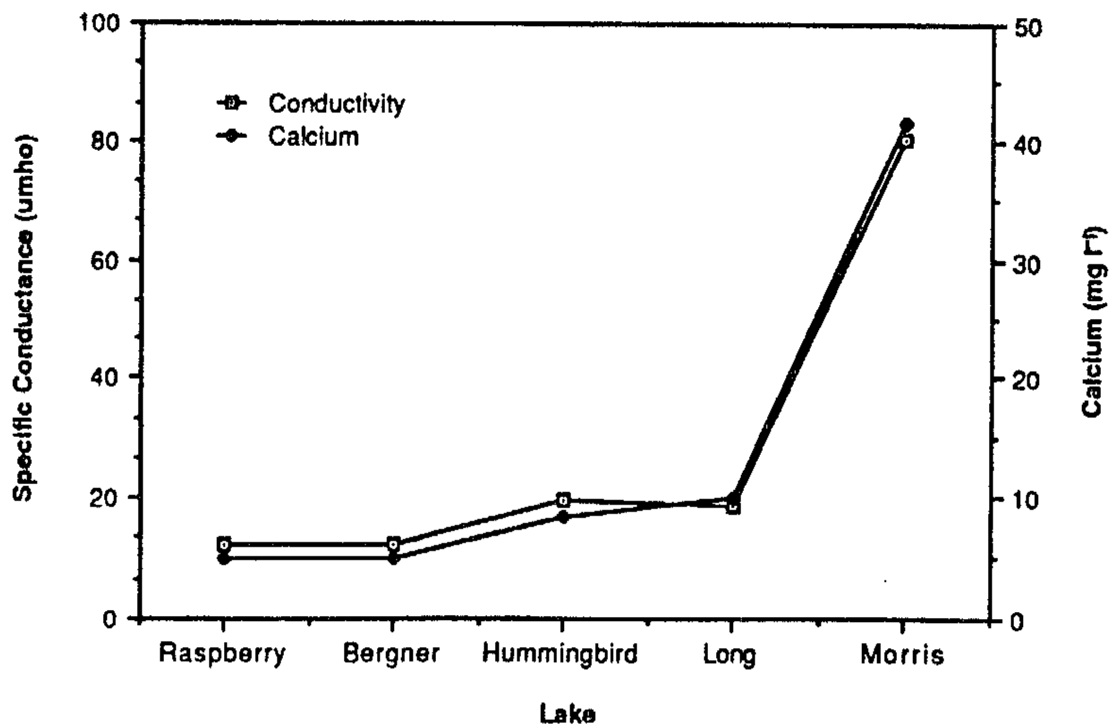


Fig.5 Specific conductance of the lakewater as an indicator of calcium content.

optimal fish productivity, according to the European Inland Fisheries Advisory Commision of 1969 (Fromm 1980).

General Ichthyological Profiles. Figures 6 through 15 illustrate length-weight relationships and age class distributions for the yellow perch populations in each of the individual lakes. The charts are included in order to give the reader a general profile of the structures and conditions of the populations used in this study. (The value R in the equation of each graph is a measure of curve fit; the best fit will have an R of 1.00.)

Relationship of fish growth to lake chemistry. Table 2 presents the collective data relating lake chemistry to fish growth. The two criteria I selected in order to compare growth among the different fish populations are: a) average length of the four-year-old fish, and b) average condition factor.

Both of these physical parameters have evenly-spread values across the five lakes (see Table 2). It was not possible to establish a positive correlation between these and the lakewater calcium contents simply because the calcium levels did not exhibit a similar spread over the five lakes (as opposed to the pH levels - see Table 2). Rather, all of them except one were very small and close together, and the one exception - that in Morris - was extremely high in comparison.

In contrast, both the average length of the four-year-olds and the populational condition factor are seen to increase consistently with increasing pH, as illustrated in Figures 16 and 17. The direct correlation between average length and lake pH is especially evident.

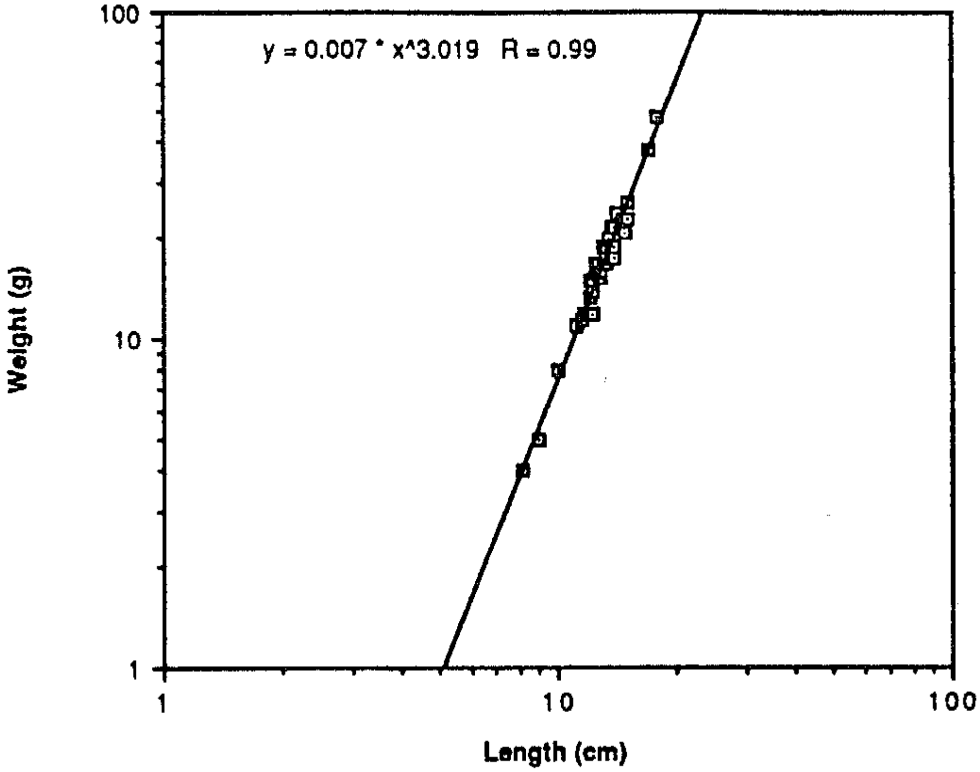


Fig.6 Growth pattern of yellow perch in Bergner Lake. Sizes ranged from 8.2cm 4g to 17.9cm 48g.

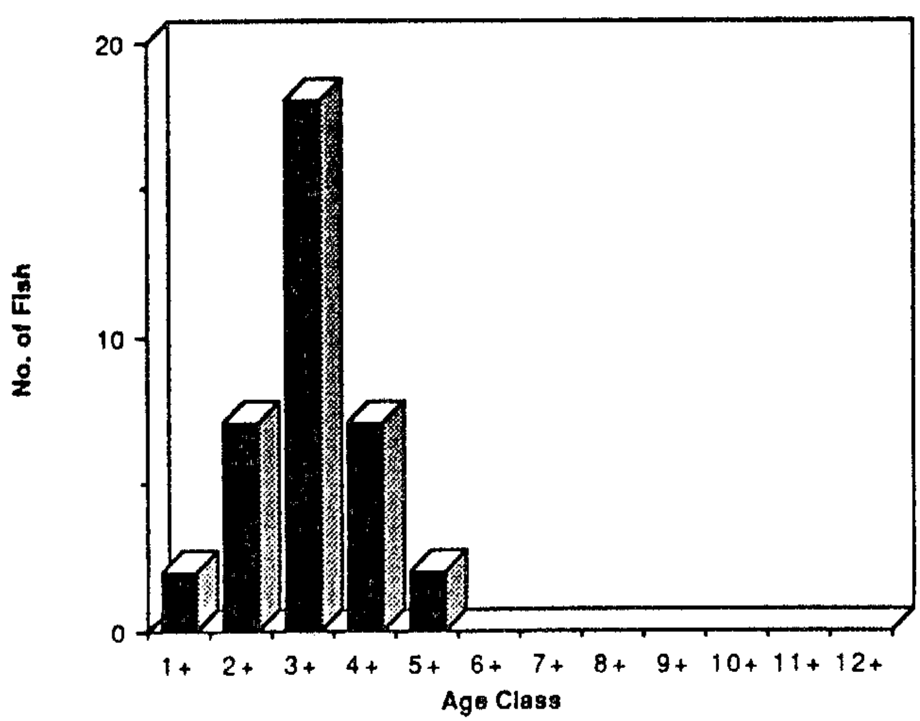


Fig.7 Age class distribution of yellow perch in Bergner Lake. No fish above the age of five were caught with either fyke or minnow nets.

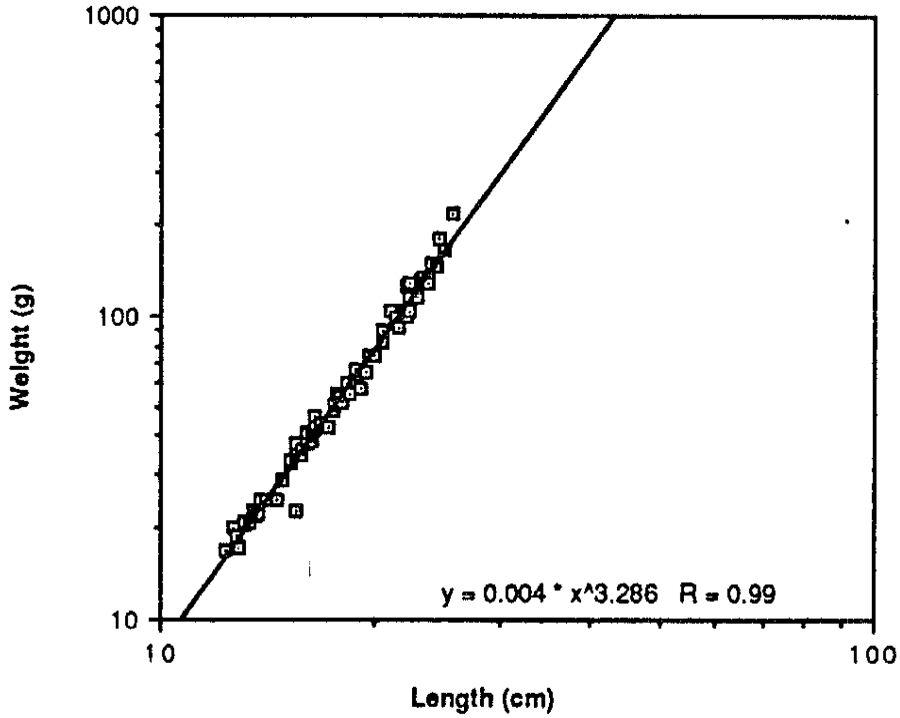


Fig.8 Growth pattern of yellow perch in Hummingbird Bog. Sizes ranged from 12.3cm 17g to 25.7cm 220g.

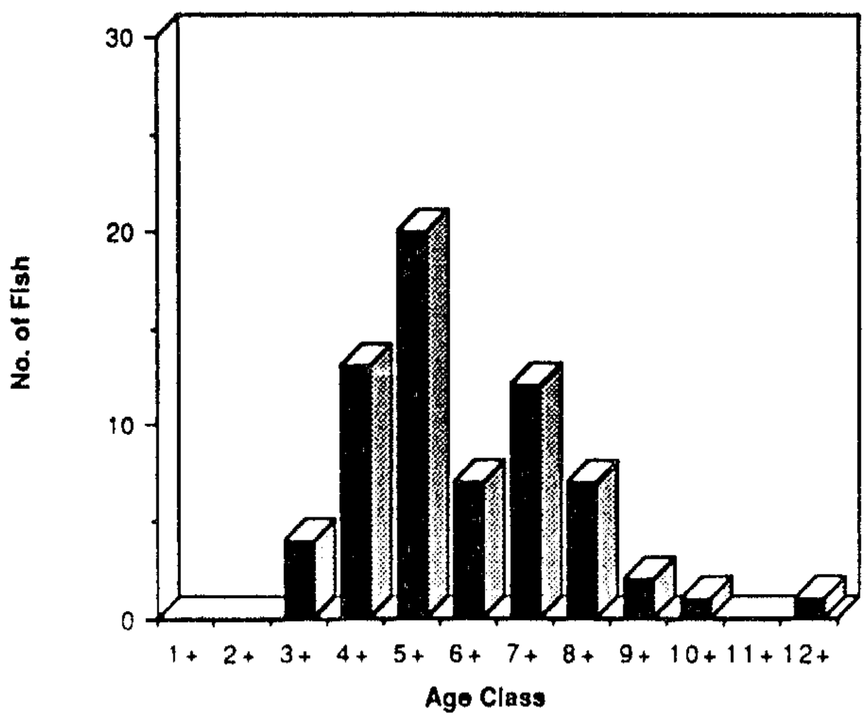


Fig.9 Age class distributions of yellow perch in Hummingbird Bog. Surprisingly, no very young fish were caught but some were observed to be as old as twelve years.

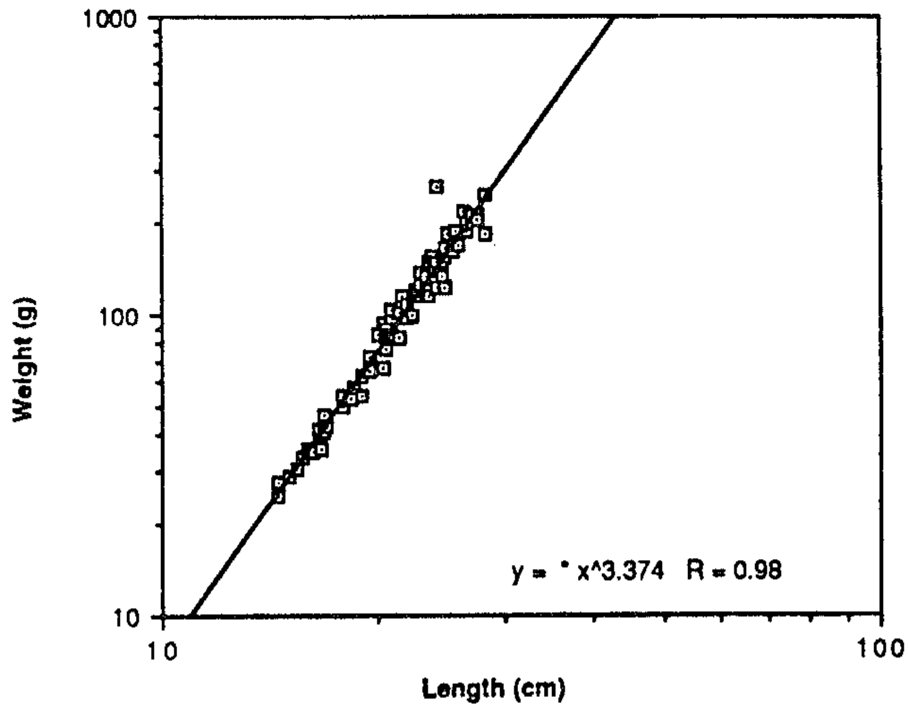


Fig.10 Growth patterns of yellow perch in Long Lake. Sizes ranged from 14.5cm 25g to 28.3cm 250g.

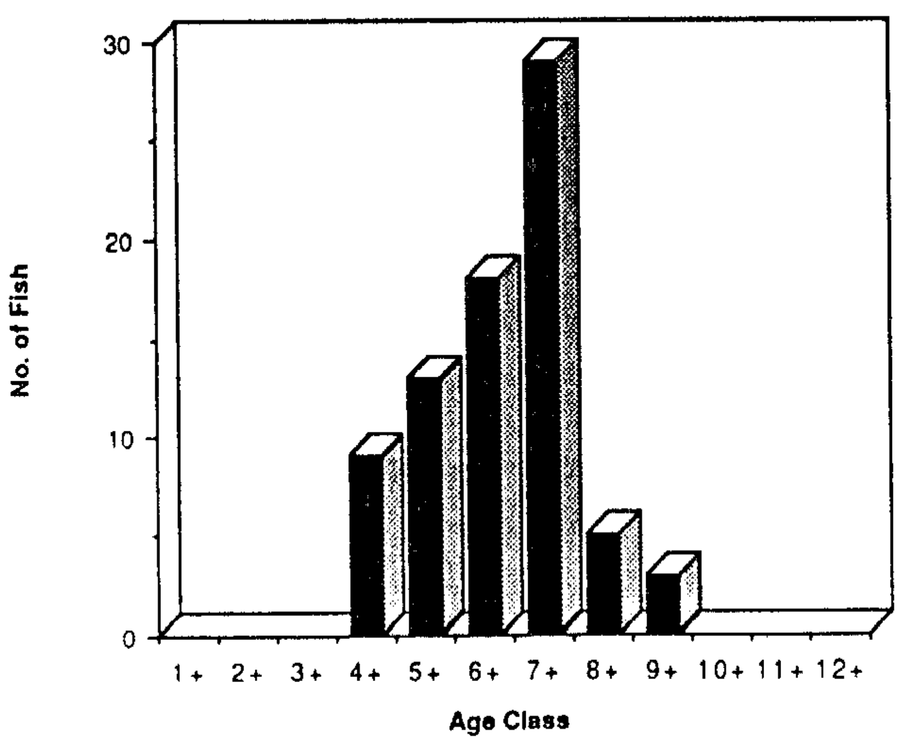
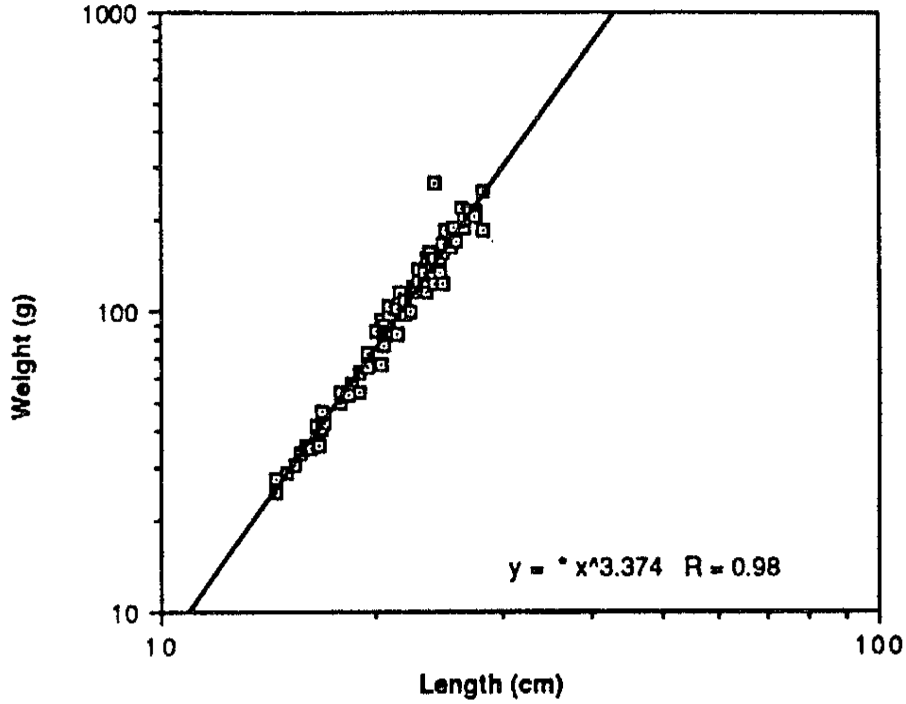


Fig.11 Age class distribution of yellow perch in Long Lake. Again, neither very young nor very old fish were captured; 7+ is the predominant age group.



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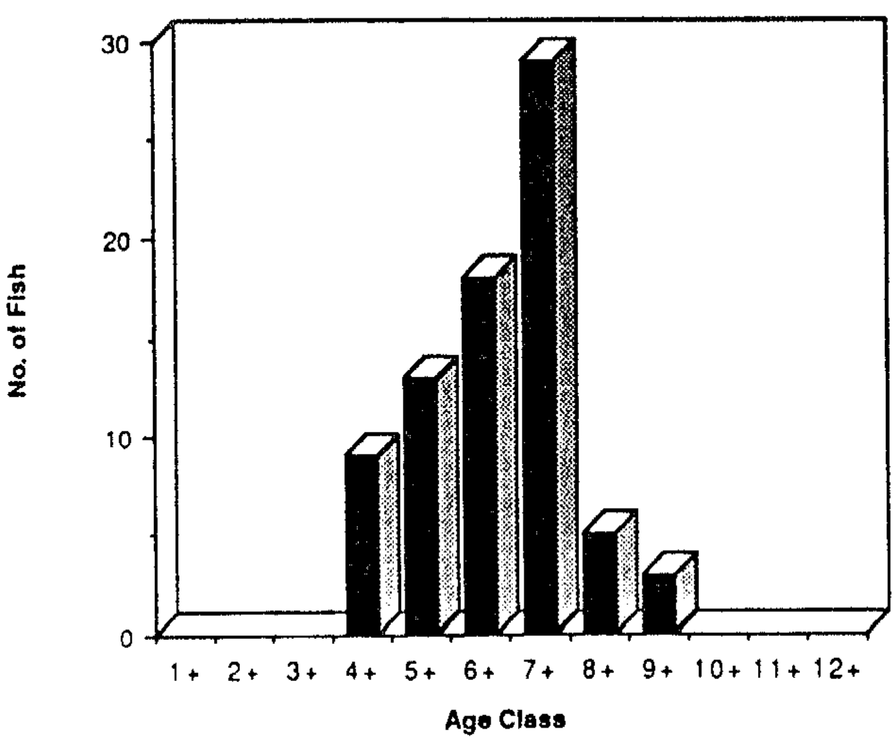

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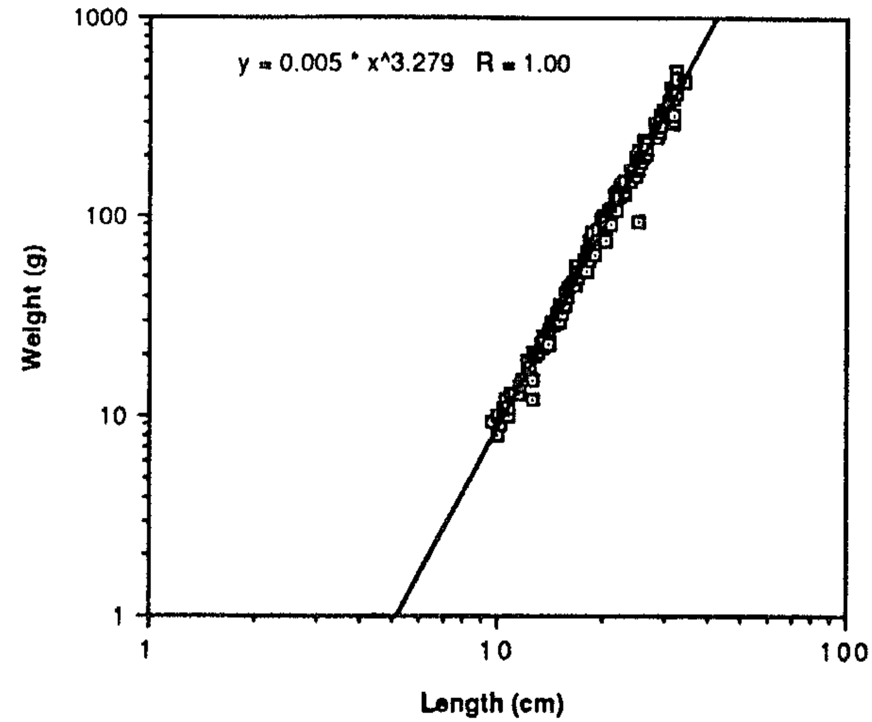

Fig.12 Growth pattern of yellow perch in Morris Lake. Sizes ranged from 9.7cm 9.5g to 34.5cm 475g.

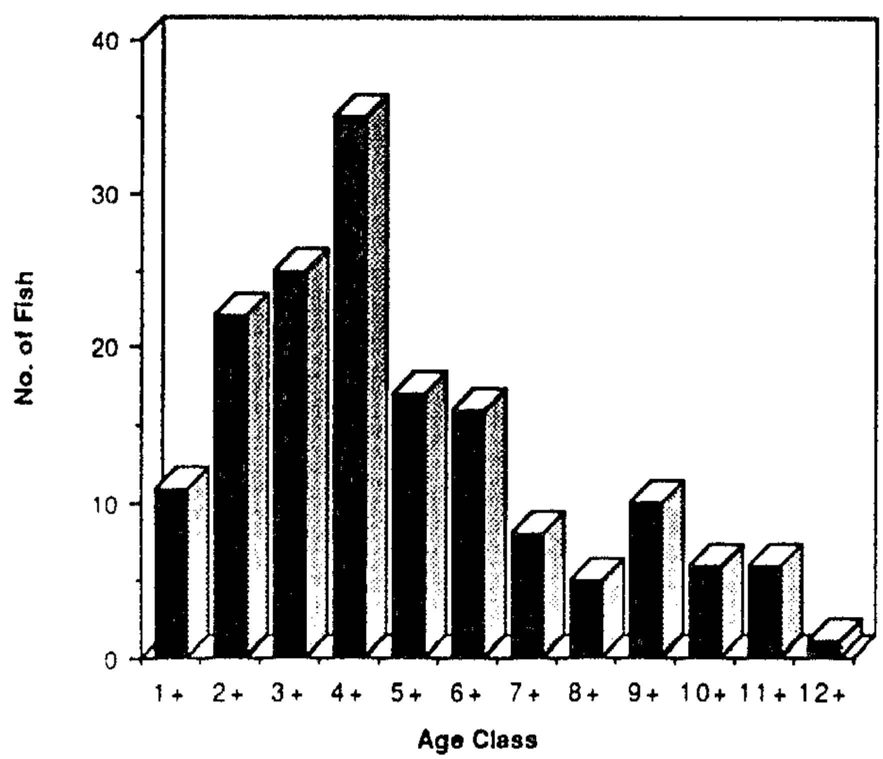

Fig.13 Age class distribution of yellow perch in Morris Lake. A relatively good range of year classes is observed.

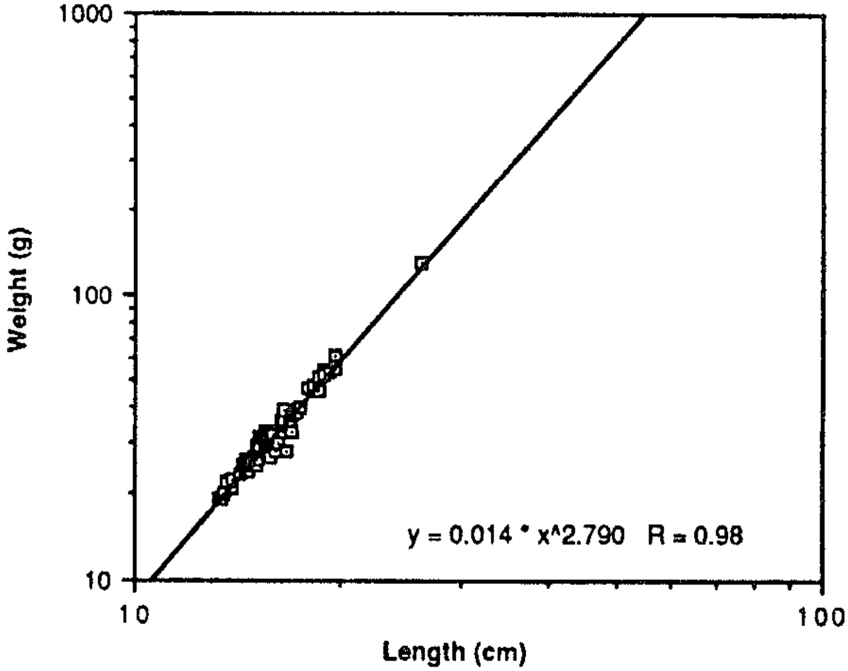

Fig.14 Growth pattern of yellow perch in Raspberry Lake. Sizes ranged from 13.2cm 19g to 26.2cm 130g.

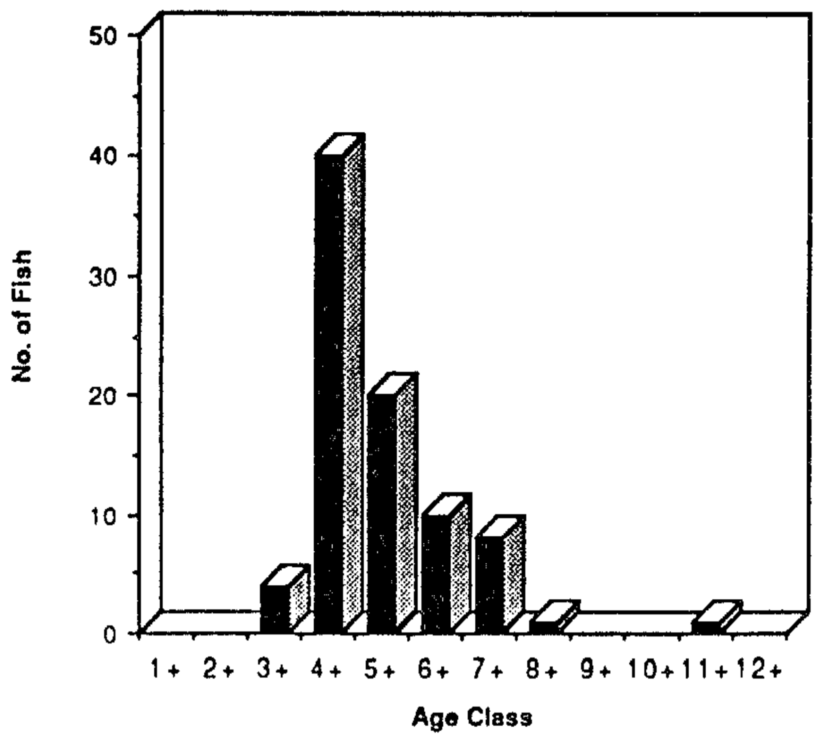

Fig.15 Age class distribution of yellow perch in Raspberry Lake. As in all the other lakes except Morris, the population is concentrated in the middle of the scale.

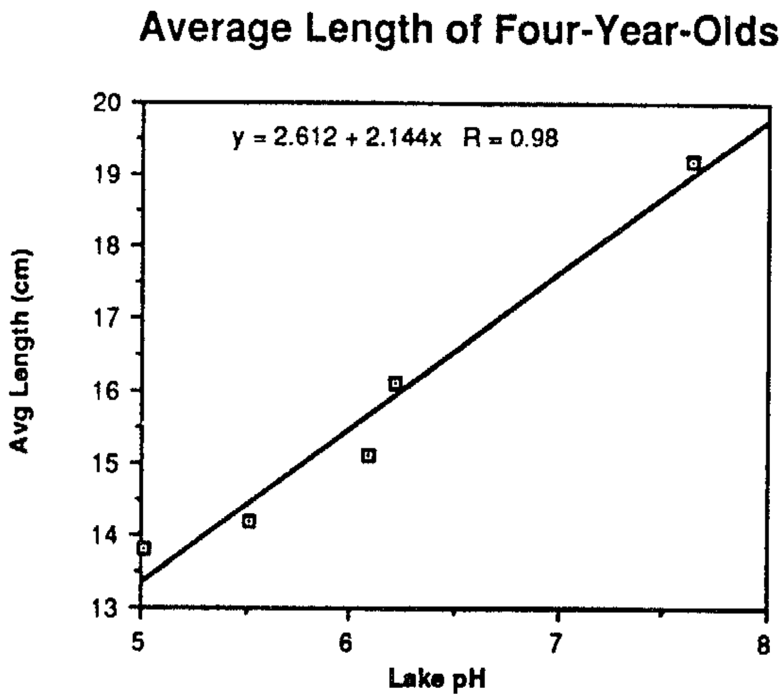

Fig.16 Average lengths of four-year-old fish in the various lakes according to pH. A relatively consistent trend is observed.

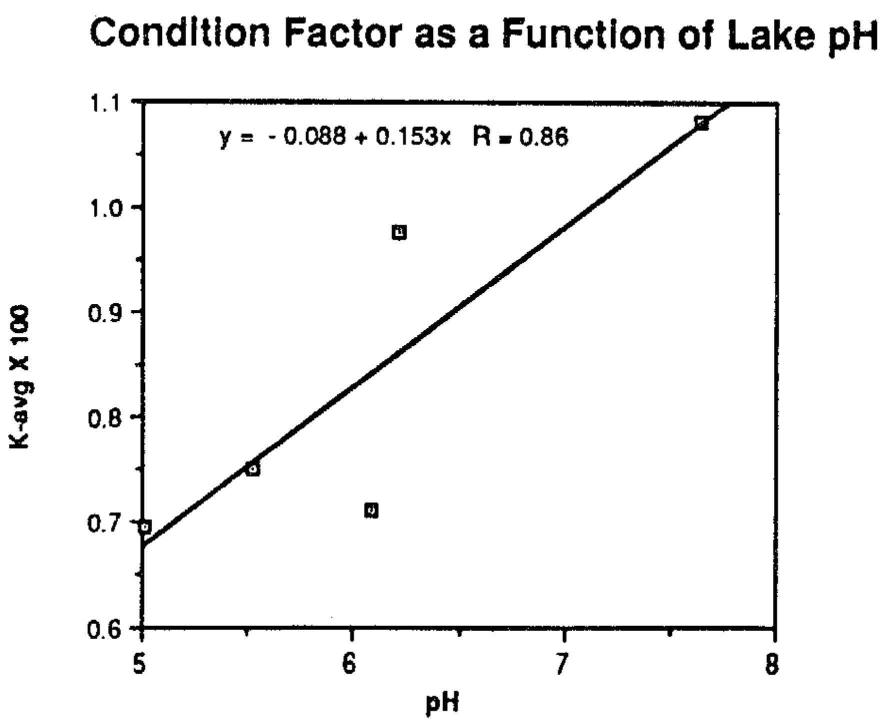

Fig.17 Populational condition factors of the perch in each lake as a function of lakewater pH. Populational condition factor (K) was computed as the mean of individual condition factors for all the perch in a given lake.

Discussion

Agreement of lake chemistry data with previous reports reflects the methods of data collection. The numbers in *A Guide to UNDERC* have been compiled from information obtained over the years by students and researchers on the property. They resemble general averages taken over all of the lakes' physical and chemical fluctuations and as such demonstrate uniform trends. The limnological information obtained for this particular study, though not longitudinal, shows similarly uniform trends because of the standardization of sites and times for data collection. Thus, while the specific values differ, by far most of the overall relationships are the same. It is not clear why Crampton and Morris Lakes gave such high pH readings this summer in comparison with their corresponding values in the handbook, although my results seem logical; Crampton is far from bog-like and this year's pH data for Morris was confirmed by a second party. The discrepancy does not merit further discussion in this paper.

Average length of a year class and average condition factor increase proportionately with increasing pH. These results, while only correlative, confirm previous unpublished observations concerning the reduced sizes of the yellow perch in the acidic lakes. The average length attained by the fourth year correlates especially well with lakewater acidity for the yellow perch on the UNDERC property. The populational condition factor (K) also seems related, despite a sizable difference between Raspberry and Long, two lakes with similar acidities. This gap may be explained by the variability of K with respect to the weight component of the equation. Raspberry Lake is teeming with yellow perch and competition for food there is keen. If the Raspberry perch food intake is unusually small, the weights will also be small, giving a smaller calculated value for the condition factor. Any such nutritional competition evidently does not affect lengths alone; this was seen in the consistency of the average length data with regard to pH.

While these facts are not evidence of a direct relationship, they are certainly at the very least indicative of an indirect one. The theory that low pH acts to decrease the food supplies would not be very plausible unless similar stunting had been observed with other fish or lake organisms, which it was not. A physiological effect of acidity on the yellow perch is far more likely because of the specificity of the target. The scope of this experiment does not allow speculation as to what exactly the physiological effect might be, but theoretically it could be a combination of many effects. From the information present calcium seems not to be directly affecting fish size because the calcium levels in Long, Raspberry, Hummingbird, and Bergner Lakes are extremely similar yet both of the myristic parameters I computed for the fish populations have significant ranges across these four lakes. What has been proved conclusively is the existence of some sort of relationship between low lakewater pH and stunted growth of yellow perch in the lakes at UNDERC.

Many age classes are missing. If low calcium is directly affecting the fish in any way we may speculate this to be through the impairment of reproductive activity (as discussed earlier in regard to pH). This could conceivably explain the marked absence of several year classes from the perch populations in certain lakes (Long, Raspberry, Hummingbird, and Bergner). This hypothesis seems plausible bacause of the very low calcium levels present in these four lakes. Such a hypothesis would be further supported by the fact that from Morris Lake - the most alkaline lake in the study - we caught representatives from every single age class through 12+.

The inconsistencies in the age classes observed in the other four lakes are puzzling. Bergner Lake year classes only go up to 5+; therefore, unless a sampling bias is in effect, it is quite possible that the acid stress on the fish is killing them off at an early age. One may nevertheless point out, with reason, that the Hummingbird fish are subjected to an even lower pH yet fish as old as 12+ were caught in the nets. One obvious ecological difference between Bergner and Hummingbird is the predatory situation; Bergner is occupied by largemouth bass (*Micropterus salmoides*) whereas the only other major fish species cohabiting Hummingbird Bog with the yellow perch is the non-piscivorous bluegill (*Lepomis macrochirus*). Whether predation by the bass is reducing the Bergner perch population early is unclear. The lakewater acidity could also have some effect upon perch metabolism, making self-defense or escape difficult for them if indeed the bass pose a predatory threat.

Hummingbird Bog had a somewhat normal age spread with only the first and second year classes missing. The theory of progressive acidification leading to a diminished spawning ability on the part of the female perch does not seem likely in this situation because the numbers of individuals across all of the year classes are randomly spaced. The same can be said of Raspberry Lake, whose age-class profile is very similar to Hummingbird's.

Long Lake is missing the 1+, 2+, 3+, 10+, 11+, and 12+ age classes in this study. This seems unlikely to represent exactly actual numbers because of recent work done by the 1987 UNDERC students finding three-and ten-year-old perch there. Nevertheless, a steady decline in number of individuals from 7+ to the most recent (4+) is observed in my study, and still no one- or two-year-olds were found. I have found no evidence to indicate progressive acidification of Long Lake over the years; in fact, I found it to be more alkaline than expected (Greene).

All of the above situations raise speculation as to the role of the calcium levels. They do not seem to correlate with growth, as pH does. However, pH does not seem to be related to the absence of year classes. Could small yearly fluctuations in already small calcium levels cause irregularities in reproductive patterns? This question goes beyond the scope of this paper and additional work with this system would be necessary in order to fully answer it.

Implications of these results for future work. It is clear that low pH is correlated to reduced fish growth in the lakes at UNDERC. Though we do not know the method by which acidity is negatively affecting the growth of yellow perch in this situation, similar studies have been made on other species of fish (see references in Introduction) and shown pH to have significant effects on them as well. Thus, while the problem at UNDERC may be unique to the yellow perch, it is even more far-reaching elsewhere. Future studies unraveling the mechanisms by which pH affects growth will help to quantify the ecological consequences of massive lake acidification and, hopefully, raise public awareness of this growing problem not only in North America but in the rest of the world.

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	A	B	C	D	E
1	MORRIS LAKE				
2	Length (cm)	9.7	10	10	10.1
3	Weight (g)	9.5	8	10	9
4	Age Class (yrs)	1 +	1 +	1 +	1 +
5	Condition Factor	0.01040899	0.008	0.01	0.00873531
6	Avg K	0.0108091			
7	Total no. fish	174			
8					
9	RASPBERRY LAKE				
10	Length (cm)	13.2	13.3	13.4	13.5
11	Weight (g)	19	19	19	20
12	Age Class (yrs)	3 +	3 +	3 +	4 +
13	Condition Factor	0.00826098	0.00807604	0.00789658	0.00812884
14	Avg K	0.0071084			
15	Total no. fish	86			
16					
17	BERGNER LAKE				
18	Length (cm)	8.2	8.9	10	11.1
19	Weight (g)	4	5	8	11
20	Age Class(yrs)	1 +	1 +	2 +	2 +
21	Condition Factor	0.00725468	0.00709251	0.008	0.00804311
22	Avg K	0.0075004			
23	Total no. fish	42			
24					
25	HUMMINGBIRD BOG				
26	Length (cm)	12.3	12.7	12.8	12.8
27	Weight (g)	17	20	18	19
28	Age Class (yrs)	3 +	4 +	3 +	4 +
29	Condition Factor	0.00913553	0.0097638	0.00858307	0.00905991
30	Avg K	0.0069581			
31	Total no. fish	72			
32					
33	LONG LAKE				
34	Length (cm)	14.5	14.5	15	15.4
35	Weight (g)	25	28	29	31
36	Age Class (yrs)	5 +	4 +	4 +	4 +
37	Condition Factor	0.00820042	0.00918447	0.00859259	0.00848789
38	Avg K	0.0097572			
39	Total no. fish	80			

	F	G	H	I	J	K
1						
2	10.3	10.5	10.6	10.6	10.7	10.8
3	11	11	10	12	10	11
4	1 +	1 +	1 +	2 +	1 +	2 +
5	0.01006656	0.00950221	0.00839619	0.01007543	0.00816298	0.00873215
6						
7						
8						
9						
10	13.6	13.8	13.9	13.9	14.2	14.4
11	22	21	21	22.5	23.5	25
12	4 +	4 +	4 +	4 +	5 +	4 +
13	0.00874593	0.00799065	0.00781943	0.00837796	0.00820735	0.00837245
14						
15						
16						
17						
18	11.2	11.5	11.7	12.1	12.1	12.2
19	11	11.5	12	13.5	15	15
20	2 +	2 +	2 +	3 +	3 +	3 +
21	0.00782958	0.00756144	0.00749245	0.0076204	0.00846711	0.0082606
22						
23						
24						
25						
26	12.9	13.1	13.1	13.3	13.5	13.5
27	17.5	20.5	21	21	22	23
28	3 +	3 +	4 +	4 +	4 +	4 +
29	0.00815209	0.00911885	0.00934126	0.00892615	0.00894173	0.00934817
30						
31						
32						
33						
34	15.7	16	16.1	16.1	16.3	16.5
35	34	36	35	36	35	40
36	5 +	4 +	4 +	4 +	4 +	4 +
37	0.00878577	0.00878906	0.00838669	0.00862631	0.00808175	0.00890447
38						
39						

	L	M	N	O	P	Q
1						
2	10.9	11.1	11.5	11.6	11.7	11.9
3	13	13	13	14	15	15
4	2 +	2 +	1 +	1 +	2 +	2 +
5	0.01003839	0.00950549	0.00854771	0.00896921	0.00936556	0.00890124
6						
7						
8						
9						
10	14.5	14.5	14.5	14.6	14.6	14.6
11	24	25	26	24	25	26
12	4 +	4 +	4 +	5 +	4 +	4 +
13	0.0078724	0.00820042	0.00852843	0.00771175	0.00803307	0.00835439
14						
15						
16						
17						
18	12.3	12.3	12.5	12.5	12.7	12.7
19	12	14	16	17	16	17
20	2 +	2 +	3 +	3 +	3 +	3 +
21	0.00644861	0.00752337	0.008192	0.008704	0.00781104	0.00829923
22						
23						
24						
25						
26	13.6	13.7	13.8	14.1	14.5	14.8
27	22	22.5	25	25	25	29
28	4 +	4 +	4 +	5 +	4 +	4 +
29	0.00874593	0.00875026	0.00951268	0.00891831	0.00820042	0.00894567
30						
31						
32						
33						
34	16.5	16.6	16.8	16.8	17	17.8
35	41.5	36.5	41	46	43	49
36	5 +	5 +	5 +	5 +	5 +	6 +
37	0.00923839	0.00797937	0.00864681	0.0097013	0.00875229	0.00868833
38						
39						

	R	S	T	U	V	W
1						
2	12.1	12.1	12.1	12.4	12.5	12.5
3	16	18	19	18	12	15
4	2 +	2 +	2 +	2 +	1 +	2 +
5	0.00903158	0.01016053	0.010725	0.00944077	0.006144	0.00768
6						
7						
8						
9						
10	14.7	14.8	14.8	14.9	15	15
11	25.5	25	26	27	25	27
12	6 +	4 +	5 +	4 +	5 +	5 +
13	0.00802765	0.00771178	0.00802026	0.00816216	0.00740741	0.008
14						
15						
16						
17						
18	12.8	12.8	12.9	13	13.1	13.2
19	15.5	16	16	17	19	17
20	3 +	3 +	3 +	4 +		3 +
21	0.00739098	0.00762939	0.00745334	0.00773782	0.00845162	0.00739141
22						
23						
24						
25						
26	15.2	15.2	15.4	15.5	15.5	15.5
27	32.5	33	34.5	23	36	38
28	4 +	5 +	5 +	4 +	5 +	5 +
29	0.00925449	0.00939687	0.0094462	0.00617636	0.00966735	0.01020442
30						
31						
32						
33						
34	17.9	18.3	18.5	18.9	19	19.4
35	54	53	57	54	63	65
36	5 +	5 +	5 +	5 +	4 +	6 +
37	0.00941531	0.00864814	0.00900243	0.0079985	0.00918501	0.00890242
38						
39						

	X	Y	Z	AA	AB	AC
1						
2	12.5	12.6	12.6	12.9	12.9	13.1
3	20	20	21	20.5	21	21
4	3 +	2 +	2 +	2 +	3 +	2 +
5	0.01024	0.00999812	0.01049803	0.00954959	0.00978251	0.00934126
6						
7						
8						
9						
10	15.1	15.1	15.1	15.1	15.2	15.2
11	26	28	28.5	29	28	29
12	3 +	4 +	4 +	4 +	4 +	4 +
13	0.00755166	0.00813256	0.00827778	0.00842301	0.0079731	0.00825785
14						
15						
16						
17						
18	13.3	13.3	13.5	13.7	13.7	13.9
19	18	19	20	19	22	19
20	3 +	3 +	3 +	3 +	4 +	3 +
21	0.00765099	0.00807604	0.00812884	0.00738911	0.00855581	0.00707472
22						
23						
24						
25						
26	15.7	15.8	16	16	16	16.3
27	35	36	38	41	41.5	38.5
28	5 +	5 +	5 +	5 +	5 +	5 +
29	0.00904418	0.00912707	0.00927734	0.01000977	0.01013184	0.00888992
30						
31						
32						
33						
34	19.5	20	20.3	20.4	20.5	20.5
35	72	87	94	60	77	84
36	5 +	6 +	6 +	7 +	6 +	6 +
37	0.00971021	0.010875	0.01123672	0.00706742	0.00893777	0.00975029
38						
39						

	AD	AE	AF	AG	AH	AI
1						
2	13.4	13.5	13.5	13.5	13.6	14
3	23	22	25	23	24	23
4	3 +	2 +	2 +	2 +	3 +	2 +
5	0.00955902	0.00894173	0.01016105	0.00934817	0.00954101	0.00838192
6						
7						
8						
9						
10	15.2	15.3	15.4	15.4	15.4	15.5
11	31	31	28	29	29	32.5
12	4 +	5 +	4 +	4 +	4 +	4 +
13	0.00882736	0.00865541	0.00766648	0.00794028	0.00794028	0.00872747
14						
15						
16						
17						
18	14	14	14.1	14.5	14.9	15
19	17.5	22	24	23	21	23
20	3 +	4 +	4 +	4 +	3 +	4 +
21	0.00637755	0.00801749	0.00856158	0.00754438	0.00634834	0.00681481
22						
23						
24						
25						
26	16.3	16.4	16.4	16.4	16.7	17.1
27	40	42	44	47	44	43
28	5 +	5 +	5 +	5 +	5 +	6 +
29	0.00923628	0.00952177	0.00997519	0.01065532	0.0094472	0.00859964
30						
31						
32						
33						
34	20.5	20.7	20.8	20.9	20.9	21.5
35	90	87	87	98	105	85
36	6 +	6 +	6 +	6 +	7 +	7 +
37	0.01044674	0.00980863	0.00966784	0.01073463	0.01150139	0.00855271
38						
39						

	AJ	AK	AL	AM	AN	AO
1						
2	14	14.2	14.4	14.5	14.7	14.8
3	27	30	30	29	33	31
4	3 +	3 +	3 +	3 +	3 +	2 +
5	0.00983965	0.01047747	0.01004694	0.00951249	0.01038872	0.00956261
6						
7						
8						
9						
10	15.5	15.5	15.6	15.6	15.6	15.6
11	28	29	30	27	28	29
12	4 +	4 +	4 +	4 +	4 +	4 +
13	0.00751905	0.00778759	0.00790219	0.00711197	0.00737538	0.00763878
14						
15						
16						
17						
18	15	17	17.9			
19	26	38	48			
20	4 +	5 +	5 +			
21	0.0077037	0.00773458	0.00836917			
22						
23						
24						
25						
26	17.5	17.5	17.6	17.8	17.9	18.2
27	49	51	55.5	54	52	60
28	5 +	5 +	6 +	6 +	5 +	5 +
29	0.00914286	0.00951603	0.01018017	0.00957489	0.0090666	0.00995261
30						
31						
32						
33						
34	21.5	21.6	21.9	22	22.3	22.4
35	102	115	108	98	100	115
36	7 +	6 +	5 +	6 +	7 +	7 +
37	0.01026325	0.01141134	0.01028233	0.00920361	0.00901748	0.01023184
38						
39						

	AP	AQ	AR	AS	AT	AU
1						
2	15	15	15.3	15.4	15.5	15.5
3	30	36	33	36	36.5	41
4	2 +	3 +		3 +	3 +	3 +
5	0.00888889	0.01066667	0.00921382	0.0098569	0.00980162	0.01101004
6						
7						
8						
9						
10	15.6	15.6	15.6	15.6	15.7	15.7
11	29.5	30	31	32.5	28	30
12	4 +	4 +	4 +	4 +	4 +	4 +
13	0.00777049	0.00790219	0.0081656	0.00856071	0.00723534	0.00775215
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26	18.4	18.8	18.8	19	19.4	19.5
27	55	64	67	58	65	75
28	6 +	6 +	7 +	6 +		
29	0.00882895	0.00963178	0.01008327	0.00845604	0.00890242	0.0101148
30						
31						
32						
33						
34	22.5	22.5	22.8	22.9	22.9	22.9
35	115	120	120	127	128	139
36	7 +	6 +	7 +	6 +	7 +	7 +
37	0.01009602	0.01053498	0.01012457	0.01057541	0.01065868	0.01157466
38						
39						

	AV	AW	AX	AY	AZ	BA
1						
2	15.8	16	16	16.2	16.4	16.5
3	40	42	43	45	47	46
4	4 +	3 +	4 +	3 +	3 +	3 +
5	0.01014119	0.01025391	0.01049805	0.01058443	0.01065532	0.01024014
6						
7						
8						
9						
10	15.7	15.7	15.8	15.8	15.8	15.9
11	30.5	32	27	29	31	29.5
12	4 +	5 +	4 +	5 +	4 +	4 +
13	0.00788135	0.00826896	0.0068453	0.00735236	0.00785942	0.00733889
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26	19.9	20.4	20.4	20.5	21	21.3
27	74	84	90	83	105	100
28	6 +	7 +	7 +	7 +	7 +	7 +
29	0.00939015	0.00989438	0.01060113	0.00963422	0.01133787	0.01034811
30						
31						
32						
33						
34	23	23.3	23.4	23.5	23.5	23.6
35	126	130	135	120	150	115
36	6 +	7 +	6 +	6 +	7 +	6 +
37	0.01035588	0.01027722	0.01053625	0.00924651	0.01155813	0.00874907
38						
39						

	BB	BC	BD	BE	BF	BG
1						
2	16.8	16.8	16.8	16.8	17	17.1
3	45	48	50	57	49	50
4	4 +	3 +	3 +	3 +	4 +	4 +
5	0.0094904	0.0101231	0.01054489	0.01202118	0.00997354	0.00999958
6						
7						
8						
9						
10	15.9	15.9	16	16.1	16.3	16.3
11	31	32	28	30	34	36
12	4 +	5 +	5 +	5 +	5 +	6 +
13	0.00771206	0.00796083	0.00683594	0.00718859	0.00785084	0.00831265
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26	21.5	22	22.1	22.2	22.3	22.4
27	92	105	125	100	105	115
28	7 +	7 +	7 +	7 +	7 +	7 +
29	0.00925705	0.00986101	0.01158066	0.00913989	0.00946836	0.01023184
30						
31						
32						
33						
34	23.7	23.9	24	24	24.1	24.2
35	155	135	145	150	150	125
36	7 +	7 +	7 +	7 +	7 +	7 +
37	0.01164358	0.00988872	0.010489	0.01085069	0.01071618	0.00881991
38						
39						

	BH	BI	BJ	BK	BL	BM
1						
2	17.2	17.5	17.6	18	18	18
3	51	52	60	52	64	66
4	3 +	3 +	3 +	3 +	3 +	4 +
5	0.0100227	0.00970262	0.01100559	0.00891632	0.01097394	0.01131687
6						
7						
8						
9						
10	16.4	16.5	16.5	16.5	16.6	16.7
11	33	33	36	39	28	34.5
12	5 +	5 +	5 +	6 +	5 +	6 +
13	0.00748139	0.00734619	0.00801402	0.00868186	0.00612116	0.00740747
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25						
26	22.4	23	23.1	23.3	23.5	23.7
27	130	115	133	135	130	135
28		8 +	8 +	8 +	8 +	8 +
29	0.01156643	0.0094518	0.01078986	0.0106725	0.01001705	0.01014119
30						
31						
32						
33						
34	24.2	24.5	24.5	24.8	24.8	24.9
35	265	135	150	125	155	167
36	7 +	7 +	7 +	7 +	7 +	7 +
37	0.0186982	0.00917985	0.01019983	0.00819511	0.01016194	0.01081729
38						
39						

	BN	BO	BP	BQ	BR	BS
1						
2	18.1	18.1	18.2	18.3	18.5	18.5
3	53	59	75	68	59	64
4	4 +	4 +	4 +	4 +	4 +	4 +
5	0.008938	0.00994984	0.01244077	0.01109572	0.0093183	0.01010799
6						
7						
8						
9						
10	16.7	16.8	16.8	16.9	16.9	17
11	35	35	36	33	37	39
12	6 +	5 +	6 +	5 +	6 +	6 +
13	0.00751482	0.00738142	0.00759232	0.00683681	0.00766552	0.00793812
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25						
26	23.8	23.9	24.4	24.5	24.9	25.7
27	130	150	145	180	165	220
28	8 +	8 +	9 +	10+	9 +	12+
29	0.00964301	0.01098747	0.00998156	0.0122398	0.01068774	0.01296055
30						
31						
32						
33						
34	25.1	25.4	25.7	25.7	25.8	25.9
35	185	163	180	190	170	170
36	8 +	7 +	7 +	7 +	7 +	7 +
37	0.01169905	0.00994687	0.01060408	0.0111932	0.00989897	0.00978475
38						
39						

	BT	BU	BV	BW	BX	BY
1						
2	18.5	18.5	18.5	18.6	18.7	18.8
3	68	71	75	73	67	66
4	4 +	4 +	4 +	4 +	4 +	5 +
5	0.01073974	0.01121355	0.0118453	0.01134447	0.0102459	0.00993277
6						
7						
8						
9						
10	17.2	17.4	17.8	18.2	18.5	18.5
11	38	40	47	48	46	51
12	7 +	7 +	6 +	7 +	7 +	8 +
13	0.0074679	0.00759298	0.0083337	0.00796209	0.00726512	0.0080548
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34	26	26.4	26.5	26.7	27.1	27.5
35	170	220	190	200	215	215
36	8 +	8 +	9 +	8 +	8 +	9 +
37	0.00967228	0.01195669	0.01020977	0.01050742	0.01080266	0.01033809
38						
39						

	BZ	CA	CB	CC	CD	CE
1						
2	18.8	18.9	19	19.4	19.5	19.8
3	83	63	73	77	85	88
4	4 +	4 +	4 +	4 +	4 +	4 +
5	0.01249121	0.00933158	0.01064295	0.01054595	0.01146344	0.01133671
6						
7						
8						
9						
10	18.8	18.9	19.2	19.5	19.5	26.2
11	55	52	54	54.6	61	130
12	7 +	7 +	7 +	6 +	7 +	11 +
13	0.00827731	0.00770226	0.00762939	0.00736358	0.00822671	0.00722836
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34	27.6	28.2	28.3			
35	205	187	250			
36	9 +					
37	0.00975049	0.00833862	0.01103013			
38						
39						

	CF	CG	CH	CI	CJ	CK
1						
2	20	20.2	20.2	20.3	20.3	20.4
3	94	87	100	85	90	76
4	4 +	5 +	4 +	4 +	4 +	2 +
5	0.01175	0.01055517	0.01213238	0.01016087	0.01075857	0.00895206
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	CL	CM	CN	CO	CP	CQ
1						
2	20.5	20.5	20.5	20.6	20.9	21
3	90	88	91	100	105	90
4	4 +	4 +	4 +	4 +	4 +	4 +
5	0.01044674	0.01021459	0.01056282	0.01143927	0.01150139	0.00971817
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	CR	CS	CT	CU	CV	CW
1						
2	21	21.2	21.3	21.5	21.5	21.8
3	110	92	110	110	128	125
4	4 +	4 +	5 +	5 +	5 +	5 +
5	0.01187777	0.00965562	0.01138293	0.01106821	0.01287937	0.01206537
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	CX	CY	CZ	DA	DB	DC
1						
2	22	22	22.3	22.4	22.5	22.8
3	105	135	135	140	125	145
4	4 +	5 +	5 +	5 +	5 +	5 +
5	0.00986101	0.01267844	0.0121736	0.01245615	0.01097394	0.01223386
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	DD	DE	DF	DG	DH	DI
1						
2	22.9	23	23	23	23.2	23.9
3	140	130	135	140	150	175
4	5 +	5 +	4 +	5 +	5 +	5 +
5	0.01165793	0.01068464	0.01109559	0.01150653	0.01201233	0.01281871
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	DJ	DK	DL	DM	DN	DO
1						
2	24	24.2	24.4	24.8	24.9	25
3	150	160	170	160	200	165
4		6 +	6 +	6 +	6 +	6 +
5	0.01085069	0.01128948	0.01170252	0.01048975	0.01295484	0.01056
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	DP	DQ	DR	DS	DT	DU
1						
2	25.2	25.4	25.4	25.4	25.5	25.5
3	170	95	175	190	180	215
4	6 +	6 +	6 +	6 +	6 +	7 +
5	0.010623	0.00579726	0.01067916	0.01159451	0.01085555	0.01296636
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	DV	DW	DX	DY	DZ	EA
1						
2	25.6	25.8	25.8	26	26.1	26.2
3	195	190	205	200	210	245
4	6 +	6 +	6 +	6 +	6 +	7 +
5	0.01162291	0.01106355	0.01193699	0.01137915	0.0118113	0.01362267
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	EB	EC	ED	EE	EF	EG
1						
2	26.3	26.5	26.6	26.7	26.8	28.2
3	220	240	210	235	220	285
4	7 +	7 +	6 +	7 +	5 +	7 +
5	0.0120936	0.01289655	0.01115769	0.01234622	0.01142926	0.01270859
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	EH	EI	EJ	EK	EL	EM
1						
2	28.4	28.6	28.9	29	29	29.3
3	300	255	280	270	285	330
4	7 +	7 +	8 +	8 +	8 +	
5	0.01309683	0.01090039	0.01160017	0.01107056	0.0116856	0.01311931
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	EN	EO	EP	EQ	ER	ES
1						
2	29.6	30	30.2	30.2	30.5	30.5
3	345	325	330	335	330	345
4	9 +	8 +	10+	9 +	9 +	9 +
5	0.01330283	0.01203704	0.011981	0.01216253	0.01163093	0.01215961
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	ET	EU	EV	EW	EX	EY
1						
2	30.8	31	31	31	31.3	31.5
3	350	345	380	385	445	330
4	9 +	9 +	10+	10+	9 +	9 +
5	0.01197887	0.01158068	0.01275553	0.01292337	0.01451199	0.01055802
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	EZ	FA	FB	FC	FD	FE
1						
2	31.5	31.5	31.7	31.8	31.8	32
3	410	420	430	295	305	390
4	9+	10+	11+	8+	10+	11+
5	0.01311753	0.01343747	0.01349866	0.00917362	0.00948459	0.01190186
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37				#DIV/0!	#DIV/0!	#DIV/0!
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	FF	FG	FH	FI	FJ	FK
1						
2	32.1	32.1	32.2	32.4	32.7	34
3	325	430	540	500	425	475
4	9+	11+	11+	10+	11+	12+
5	0.00982581	0.0130003	0.01617432	0.0147006	0.01215474	0.01208528
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37	#DIV/0!					
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	FL	FM	FN	FO	FP	FQ
1						
2	34.5					
3	475					
4	11+					
5	0.01156742					
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