

Frog Populations Among Four North Temperate  
Bogs of Different pH Values

BIOS 569 - Practicum in Aquatic Biology

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## Frog Populations

### ABSTRACT

The purpose of this study was to determine if there is an association between pH and aluminum concentrations with frog diversity among four bogs at the University of Notre Dame Environmental Research Center (UNDERC). The study, May 16 - July 20, 1994, has shown a correlation of certain frog species with certain bog environments, specifically in regard to pH. Certain frog species appear to be more sensitive to slight changes in pH. Each bog that was in a definite pH range had a characteristic frog population. Results were not consistent with aluminum concentration, no discernable patterns were discovered. Catch and release methods combined with observation showed that frogs populated these four bogs in relation to the bog's pH.

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# Frog Populations

## I. INTRODUCTION

Frog populations have been declining over a number of decades. Much research has focused on relating this decline with decreased pH levels and increased levels of dissolved toxic metals (Dunson and Connell 1982). This increased acidity affects all frog developmental stages.

High egg mortality, leading to changes in adult population, could be occurring in a number of ways. At lower pH values, the egg masses are more likely to be overcome by a fungus that will prevent the eggs from escaping once hatched (Pough 1976). The high hydrogen ion concentration may deactivate the hatching enzyme responsible for the normal breakdown of the egg membrane (Dunson and Connell 1982). Furthermore, low pH environments may not supply sufficient oxygen for the development of the embryo due to a lack of affinity of water for oxygen in an acidic environment. Tadpole death results largely from an inability to maintain proper ion stability in low pH conditions (Freda and Dunson 1983).

Previous studies on size and mortality rates of both eggs and tadpoles show a positive correlation between decreased pH and increased aluminum concentrations (Dale, Freedman, and Kerekes 1984). Assuming that these differences will carry on into the adult population, the decrease in pH and increase in aluminum may cause the frogs to have different reproductive and survival rates. This should be apparent in field studies. Bog habitats provide an ideal stage for this type of study because of their naturally acidic waters.

The two main goals of the research were as follows: to make a rough population, size, and density estimate in each of the four bogs, and to make observations concerning the types of species present compared to pH and aluminum levels. Theories will then be put forth as to why and how such trends occur, which will lead into a discussion about future research areas.

## Frog Populations

Special interest was on the chemical properties of Reddington Bog in Goegebic County, Michigan. In the summer of 1993 research on Reddington Bog showed chemical differences when compared to similar bodies of water in the same area (Graham, unpublished 1993). Reddington's meromictic waters were determined to be acidic with a high hypolimnetic sulfide content.

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### II. SPECIES STUDIED

1. Rana pipiens (Northern Leopard frog) a brown or green frog 5.1 - 8.9 cm with 2 or 3 rows of irregularly placed dark spots with light borders between conspicuous dorsolateral ridges. In summer it can be found away from the water.
2. Rana septentrionalis (Mink frog) is 4.8 - 7.0 cm in length and has variable dark spots. When the frog is rubbed, the skin produces a distinctive odor.
3. Rana sylvatica (Wood frog) has a characteristic "robber's mask" or dark spot around each eye. The length ranges from 3.5 - 7.0 cm.
4. Rana clamitans (Green frog) green to greenish-brown, measuring 4.6 - 7.5 cm with dorsal spots forming lines on the legs of the frog.
5. Bufo americanus (American toad) has skin spotted with dark pigment, warts, and a paratoid gland likely separated from the eye.

## Frog Populations

### III. MATERIALS AND METHODS

#### A. Preliminary Data Collection

Ed's Bog, North Gate Bog, Tender Bog, and Reddington Bog were studied on the University of Notre Dame's Environmental Research Center (UNDERC) from May 16 through July 20 1994 by Dan Thuente, Brendan Kilbane, and Liz Broghammer under the direction of Dr. Hellenthal.

Topographic maps were constructed for Reddington and North Gate bogs.

Chemical analyses of the four bogs were performed on May 29th and July 16th. A Hach spectrophotometer was used for the analysis. The following concentrations were determined: alkalinity, using the buret titration method; color, using the platinum-Cobalt Standard method; conductivity, using the Direct Measurement method; aluminum, using the low range reduction method; nitrate, using the high range Cadmium method; phosphate, using the high range reactive phosphorus phosver 3 method; hydrogen sulfide, using the low range lead sulfide method for water. During the collection of the water samples, the Dissolved Oxygen (DO) probe was used to get oxygen and temperature measurements. Two water samples were collected from each bog using the Kemmerer sampler. The samples were taken from one meter from both the surface and the bottom.

#### B. Frog Sampling

The bogs were sectioned off into pie shapes for more accurate population estimates. Maps of the bogs including the sections and approximate location within the section where the frogs were captured. The size of these sections varied according to the relative size of the particular bog. Tender Bog was divided into 14 sections at 15 meters by 4 meters, creating an area of 50 m<sup>2</sup>. Ed's Bog was divided into seven sections. They were 15 m x 25 m due to a very large bog mat creating a section size of 375 m<sup>2</sup>. North Gate was divided into 12 sections of 20 m x 3 m creating a section size of 60 m<sup>2</sup>. Reddington had 24 sections at 40 m x 12 m creating an area of 480 m<sup>2</sup>. Reddington's

## Frog Populations

lag was the only part sectioned off because this was the only place frogs were seen during this study.

Capture techniques evolved and improved with experience as the summer progressed. Only a few tadpoles were seen; therefore, they could not be sampled. The first three sampling periods employed the hand capture technique. This technique did not work well unless the frogs were on a solid bog mat. Nets were used for the majority of the summer. These enabled underwater capture, a much greater reach, and an increased success rate.

Specific frog search times were set for each bog: Tender - 20 min./section; Ed's - 20 min./section; North Gate - 20 min./section; Reddington - 30 min./section. These times were set based on the area covered, but more importantly on the area type. Certain bog mats were easier to search and had a lower search time than would be expected for their given size. During this set time, everything seen was attempted to be captured. Size, weight, sex, and species type were recorded. If the frogs escaped, the species, approximate length, and section were recorded. Twice at the end of the summer, to allow for newly emerged frogs to be significant, a group was gathered for a massive search to obtain an approximate census. For Tender, Ed's, and North Gate Bogs, six people circled each entire bog catching frogs. For Reddington, only six sections were used, then this data could be extrapolated into a total population number. From this data a calculated frog/person/minute ratio was determined to get an estimate of density, and the length and weight measurements were averaged.

## Frog Populations

table 1

May 29, 1994	Tender top	Tender bottom	Ed's top	Ed's bottom	North Gate top	North Gate bottom	Redd. top	Redd. bottom
Alkalinity	0	0	0	0	0	0	0	0
pH	4.47	4.61	5.12	4.99	4.48	4.93	6.32	5.94
Color (PtCo)	198	240	86	153	199	263	186	247
Conductivity (us/cm)	35.3	29.9	27.6	17.1	27.9	27.0	27.5	47.0
Nitrate (mg/L)	1.0	1.4	0.4, 0.5	0.4, 0.7	0.9, 0.8	1.2, 1.7	0.7	1.0
Phosphate (mg/L)	0.02	0.02	0.01, 0.02	0.09, 0.08	0.08	0.07, 0.09	0.10	0.23, 0.13
Sulfate (mg/L)	0.0	0.3	0.0	0.0	0.1	0.3	0.0	0.0

## Frog Populations

Table 2

July 16, 1994	Tender top	Tender bottom	Ed's top	Ed's bottom	North Gate top	North Gate bottom	Redd. top	Redd bot.
Alkalinity	0	0	0	0	0	0	0	0
pH	4.39	4.61	4.85	4.74	4.65	5.0	6.02	5.82
Color (PtCo)	219	287	79	153	172	295	184	428
Conductivity (us/cm)	27.1	26.8	14.3	18.0	22.0	32.8	28.1	109.7
Nitrate (mg/L)	1.0	1.3	0.4	0.6	0.6	1.3	0.6	1.5
Phosphate (mg/L)	0.03	0.04	0.04	0.13	0.05	0.07	0.06	2062
Sulfate (mg/L)	0	0	0	0	0	1.0	0	0.3
Aluminum (mg/L)	0.03	0.07	0.01	0.01	0.05	0.08	0.07	0.02

Frog Populations

Table 3

Date	Tender Temp. (Celcius)	Tender pH	Ed's Temp. (Celcius)	Ed's pH	North Gate Temp. (Celcius)	North Gate pH	Redd. Temp. (Celcius)	Redd. pH
6/6	23.8	4.57	--	--	18.5	4.48	23.4	6.41
6/8	23.9	4.45	16.1	5.06	20.8	4.49	19.2	5.40
6/10	19.5	4.37	17.5	5.20	19.8	4.44	20.1	6.21
6/17	22.3	4.41	17.9	5.15	20.5	4.52	21.2	6.33
6/20	23.8	4.24	18.1	5.10	20.1	4.67	21.9	6.44
6/24	24.2	4.25	18.8	5.07	21.2	4.82	22.5	6.17
6/27	24.7	4.22	19.3	5.20	--	--	--	--
7/5	22.5	4.31	20.1	4.77	23.5	4.80	26.0	6.20
7/16	23.5	4.27	20.4	5.05	22.9	4.60	25.4	6.31

	Tender Bog	Ed's Bog	North Gate Bog	Reddington Bog
Median pH	4.37	5.07	4.60	6.31
pH range	4.22 - 4.57	4.77 - 5.20	4.44 - 4.80	5.40 - 6.44

Frog Populations

Table 4

Bog	pH	[Al]mg/L	Wood	Leopard	Mink	Green
Tender	4.34	0.03	50	0	0	4
Ed's	5.07	0.01	3	9	0	3
North Gate	4.60	0.05	0	23	0	5
Reddington	6.29	0.07	3	11	46	6

Frog Populations

Table 5.  
Tender Bog Individual Summer Frog Search

Frogs	Section	People	Time (min)	Sex	Length (cm)	Weight (g)	Date
Green	14	1	20	M	6.71	33.06	6/6
Wood	12			M	4.57	6.78	
Wood	12			M	2.70	2.13	
Wood*	12				~6.0		
Wood*	12				~6.0		
Wood*	12				~6.5		
Wood	12	1	20	M	5.1	10.73	6/8
Wood	12			F	4.4	8.77	
Wood	12			F	2.69	1.56	
Wood	12			F	2.95	1.15	
Wood	12			F	2.45	1.46	
Wood	12				~4.0		
Wood*	12				~3.0		
0	2						6/8
Wood	11	1	20	M	3.10	1.59	6/10
Wood	11			M	3.95	5.92	
Wood	11			M	3.85	4.82	
Wood	11			M	3.0	1.95	
Wood*	11				~2.0		
Wood*	11				~3.0		
Wood*	11				~2.0		
Wood*	11				~3.0		
Wood*	11				~3.0		
Wood*	11				~3.0		
Wood*	11				~2.0		
0	12	1	20				6/17
0	11	1	20				6/17
0	9	1	20				6/17
0	5	1	20				6/20
Wood*	11	1	20		~3.0		6/20
Wood*	7	1	20		~5.0		6/24
Wood*	3	1	20		~3.0		6/27
Wood	4	1	20	?	1.2	1.89	7/12
Wood	4			M	2.75	2.75	

\* seen but not captured

@ newly emerged with tail remnant

Each date represents one search period

# Frog Populations

Table 6.  
Tender Bog Group Frog Search

Frogs	Section	People	Time (min)	Sex	Length (cm)	Weight (g)	Date
Wood	12	6	20	F	3.0	3.77	7/5
Wood	12			F	2.5	3.84	
Wood	12			F	2.7	2.85	
Wood*	12				~2.0		
Wood*	12				~3.0		
Wood*	12				~3.0		
Wood*	12				~2.0		
Green*	12						
Wood	14			F	2.9	3.19	
Wood@	14			?	1.3	1.74	
Wood@	8			?	1.2	1.89	
Wood*							
Wood*							
Wood	12	6	20	?	1.1	.89	7/16
Wood	4			F	3.5	6.11	
Wood	11			M	3.9	5.06	
Wood	12			F	3.8	5.73	
Wood	11			F	3.1	3.98	
Wood*	12			F	3.4	5.02	
Wood*	11						
Wood*	11						
Wood*	12						
Wood*	12						
Green*	8						
Green*	12						

Each date represents one search period

\* seen but not captured

@ newly emerged with tail remnant

Individual Success Rate = 2.23 frogs/20 person minutes

Group Success Rate = 2.16 frogs/20 person minutes

Average Wood Frog weight = 3.68 g

Average Wood Frog length = 3.00 cm

Percentage in sector 11 and 12 = 76%

Percentage of Wood Frogs = 92.6%

Percentage of Green Frogs = 7.4%

Male:Female = 3:4

## Frog Populations

Table 7.  
Ed's Bog Individual Summer Frog Search

Frogs	Section	People	Time(min)	Sex	Length(cm)	Weight(g)	Date
Leopard*	1	1	20		~7.0		6/8
Leopard*	1				~8.0		
Leopard*	3				~10.0		
Leopard*	3				~9.0		
0	2	1	20				6/10
Leopard	2	1	20	M	5.2	11.39	6/17
Leopard*	2				~5.0		
Bufo*	2				~7.0		
Leopard*	5	1	20		~11.0		6/20
0	6	1	20				6/24
0	4	1	20				6/27
Green	1	1	20	M	3.0	6.50	7/12
Wood	1			?	1.2	1.63	
Green	1	1	20	M	3.2	7.0	7/13
Wood@	all bog				~1.0		

Each date represents one search period

Table 8.  
Ed's Bog Group Frog Search

Frogs	Section	People	Time(min)	Sex	Length(cm)	Weight(g)	Date
Leopard	6	6	20	F	7.4	34.88	7/5
Green	4			M	6.41	23.54	
Leopard*	8	6	20		~6.0		7/16
Wood@	all bog				~1.0		

Each date represents one search period

\* seen but not captured

@ newly emerged with tail remnant

Individual Success Rate = 1.25 frogs/20 person minutes

Group Success Rate = .25 frogs/20 person minutes

Average Leopard Weight = 23.1 g

Avg. Leopard Length (est) = 7.6 cm

Percentage that are Leopard = 64.2 %

Percentage that are toads = 7.1 %

Percentage that are Green = 21.4 %

Frog Populations

Table 9.  
North Gate Bog Individual Summer Frog Search

Frogs	Section	People	Time(min)	Sex	Length(cm)	Weight(g)	Date
Leopard	1	1	20	F	5.10	8.40	6/8
Leopard*	1				~5.0		
Leopard*	1				~5.0		
Leopard*	3				~7.0		
Leopard*	3				~10.0		
Leopard*	3				~10.0		
0	12	1	20				6/10
Leopard	2	1	20	M	7.2	34.41	6/17
Leopard*	2				~5.0		
Leopard*	2				~5.0		
0	4	1	20				6/20
Leopard*	12				~5.0		
Leopard*	12				~6.0		
Leopard*	10				~10.0		
Leopard*	10				~10.0		
0	6	1	20				6/24
Leopard*	10	1	20		~6.0		6/27
Bufo (thousands)	all bog						
Green	1	1	20	F	3.0	10.51	7/9
Green*	6				~9.0		
Leopard	12	1	20		~10.0		7/14

Table 10.  
North Gate Bog Group Frog Search

Frogs	Section	People	Time(min)	Sex	Length(cm)	Weight(g)	Date
Leopard	1	6	20	F	7.9	35.42	7/5
Leopard	3			F	7.5	33.45	
Leopard*	8						
Leopard*	5						
Leopard	1	6	20	F	3.9	6.58	7/16
Green	1			F	6.8	22.09	
Leopard	1			F	6.3	17.67	
Green	4			F	3.85	6.62	
Leopard*	12				~6.0		
Green*	2				~6.0		
Leopard*	3				~8.0		

\* seen but not captured

@ newly emerged with remnant tail

Individual Success Rate = 1.5 frogs/20 person minutes

Group Success Rate = .92 frogs/20 person minutes

Average Leopard Weight = 22.65 g

Avg. Leopard Length (est) = 6.34 cm

Average Green Weight = 13.07 g

Avg. Green Length (est) = 5.73 cm

Percentage of Leopard = 79.3 %

Percentage of Green = 21.7 %

## Frog Populations

Table 11.  
Reddington Individual Summer Frog Search

Frogs	Section	People	Time(min)	Sex	Length(cm)	Weight(g)	Date
Mink	24	1	30	M	6.83	25.65	6/8
Bufo	24				2.0	1.04	
Leopard*	24				~5.0		
Leopard*	24				~5.0		
Leopard*	24				~6.0		
0	22						
Leopard	10	1	30	M	5.78	12.05	6/10
Mink	10			M	6.80	25.40	
Mink	10			M	6.28	19.7	
Leopard*	10				~6.0		
Leopard*	10				~7.0		
Leopard*	10				~9.0		
Mink*	7	1	30		~5.0		6/15
Mink*	7				~5.0		
Mink*	7				~6.0		
Green*	2	1	30		-		6/17
Green*	2				-		
Green*	2				-		
Green*	2				-		
Green*	4	1	30		~4.0		6/20
Mink*	4				~5.0		
0	5						
Leopard	5			M	6.1	16.8	
Leopard	5			M	6.0	15.5	
0	24						
Mink	1	1	30	F	6.5	24.45	6/24
Mink	1			M	5.7	14.55	
Mink	1			F	6.3	17.20	
Leopard*	18	1	30		~5.0__		6/27
Bufo recently emerged							7/13
seen everywhere							

Table 12.  
Reddington Group Frog Search

Frogs	Section	People	Time(min)	Sex	Length(cm)	Weight(g)	Date
Mink	1	6	30	F	6.6	23.49	7/5
Mink	1			F	6.1	21.45	
Mink	22			F	5.85	19.14	
Mink	23			F	6.10	26.50	
Mink	24			F	7.0	23.71	
Mink	3			F	5.1	18.89	
Mink@	2			F	4.0	9.97	
Mink	3			F	4.7	14.15	
Mink	22			F	5.1	13.07	
Mink	23			F	6.1	21.96	
Mink@	2			F	3.9	11.38	
Mink@	2			F	3.5	9.68	

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Mink@	3			F	3.8	10.67
Mink@	1			F	4.2	10.66
Leopard	2	6	30	?	4.1	7.18
Mink	1			F	6.9	17.83
Mink	24			M	5.5	13.49
Mink@	23			?	3.2	6.72
Mink@	24			F	4.8	8.74
Mink@	1			F	4.5	10.21
Mink@	1			F	4.2	9.07
Mink@	23			F	4.1	8.45
Mink@	1			F	4.6	9.91
Mink@	1			F	3.9	7.18
Mink@	3			F	4.8	11.61
Mink@	23			F	3.7	6.68
Mink*	23					
Green*	24					
Mink*	23					
Mink*	1					
Wood*	2					
Wood*	2					
Wood*	2					
Mink*	2					
Mink*	2					
Mink*	2					
Mink*	2					
Mink*	24					
Mink*	24					
Mink*	24					
Mink*	23	0				

Each date represents one search period

\* seen but not captured

@ recently emerged with tail remnant

Individual Success Rate = 2.36 frogs/30 person minutes

Group Success Rate = 3.5 frogs/30 person minutes

Average Leopard Weight = 12.88 g

Avg. Leopard Length = 5.38 cm

Average Adult Mink Weight = 18.8 g

Avg. Adult Mink Length = 5.38

Mink Male:Female = 1:3

Percentage Mink = 67.6%

Percentage Green = 8.8%

Percentage Wood = 5.4%

Percentage Leopard = 16.2%

Percentage Bufo = 2.0%

# Tender Bog

## Frog Population

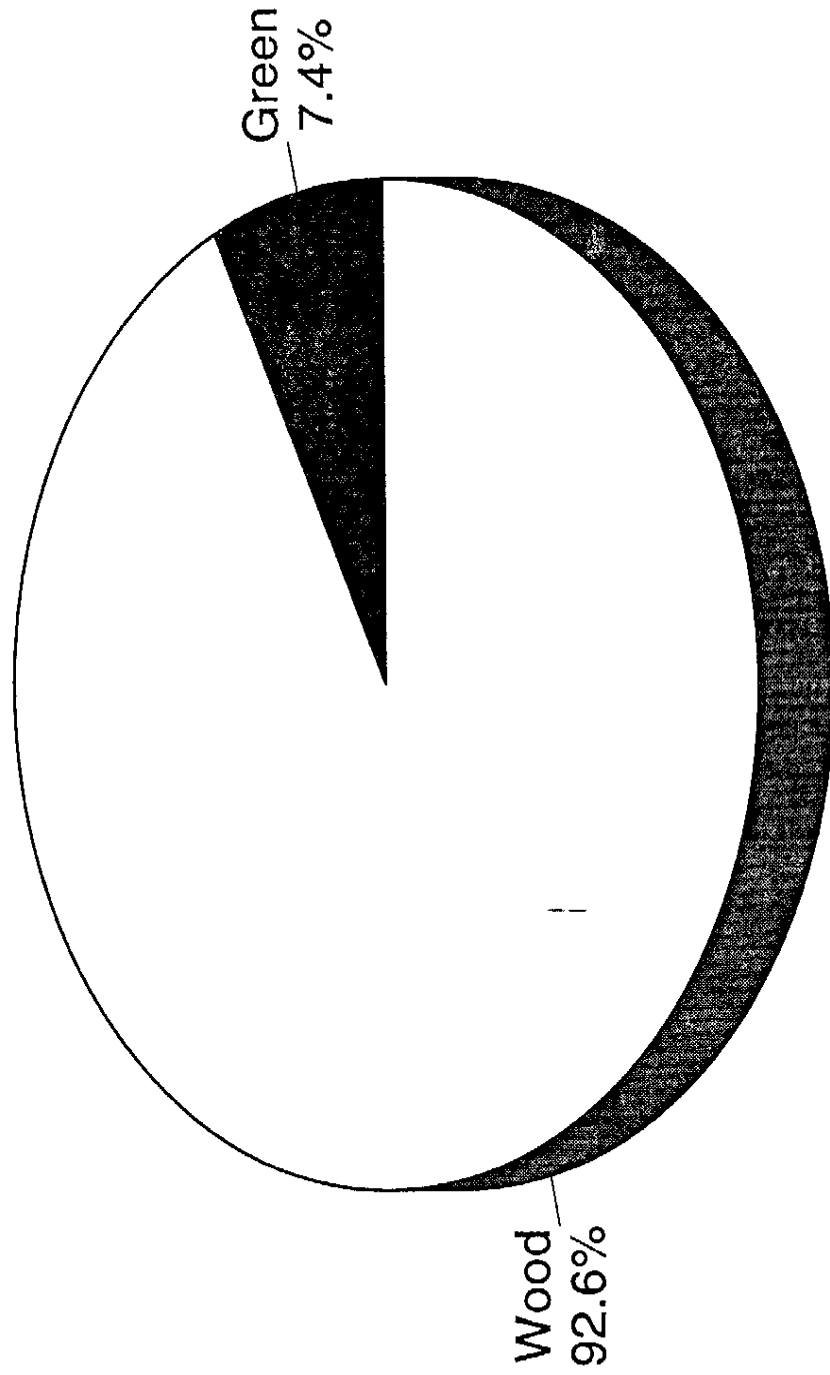


figure 1

# Ed's Bog

## Frog Population

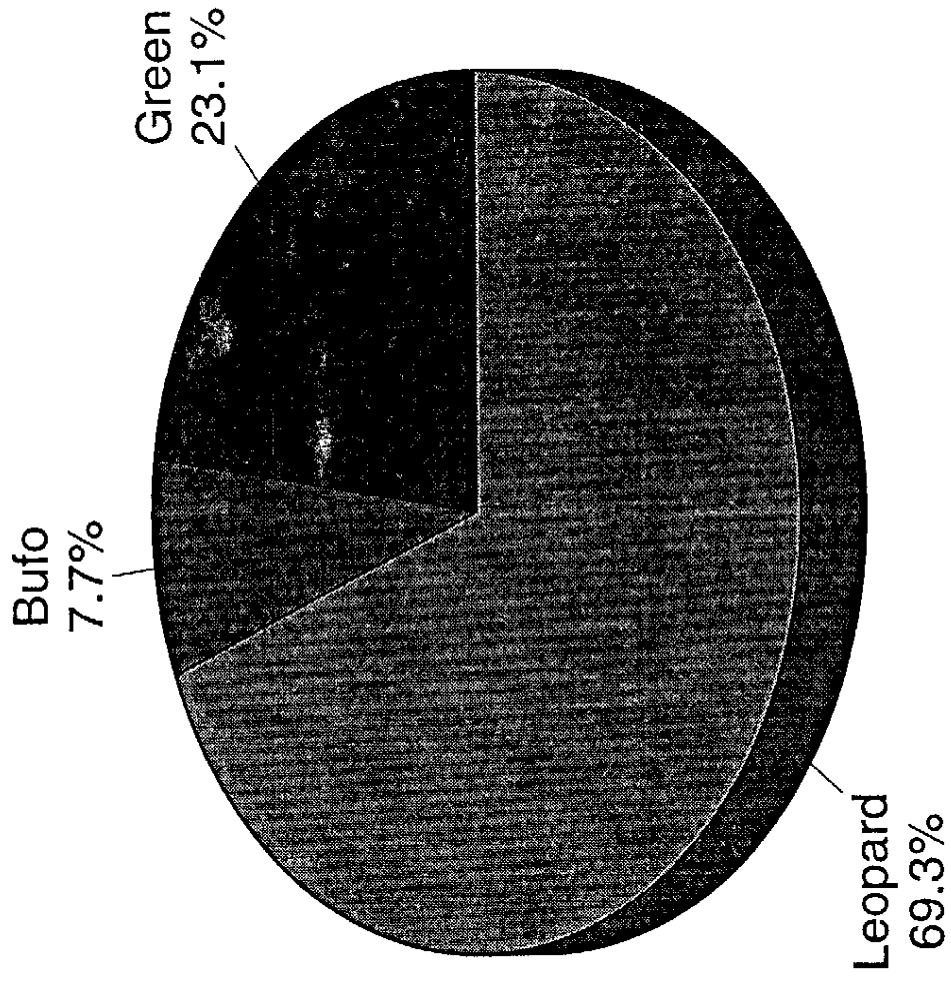


figure 2

# North Gate Bog

## Frog Population

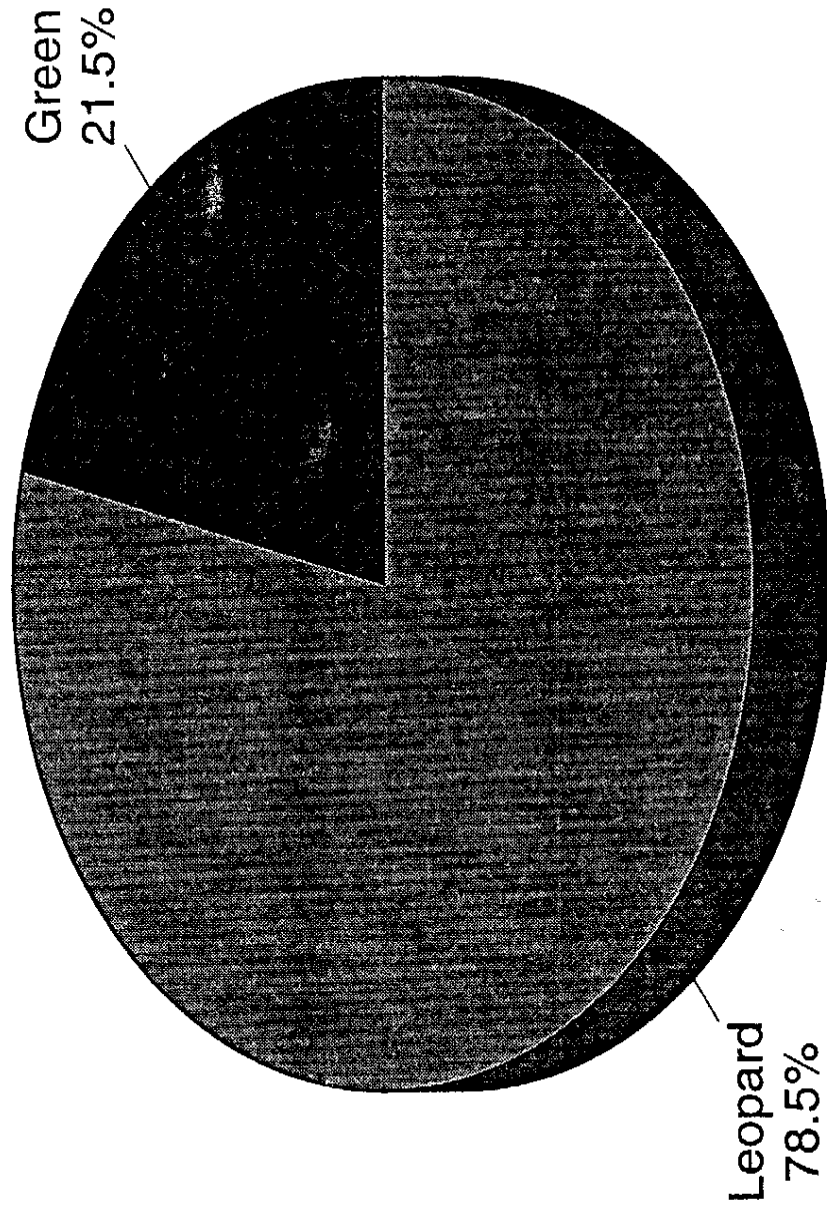


Figure 3

# Reddington Bog

## Frog Population

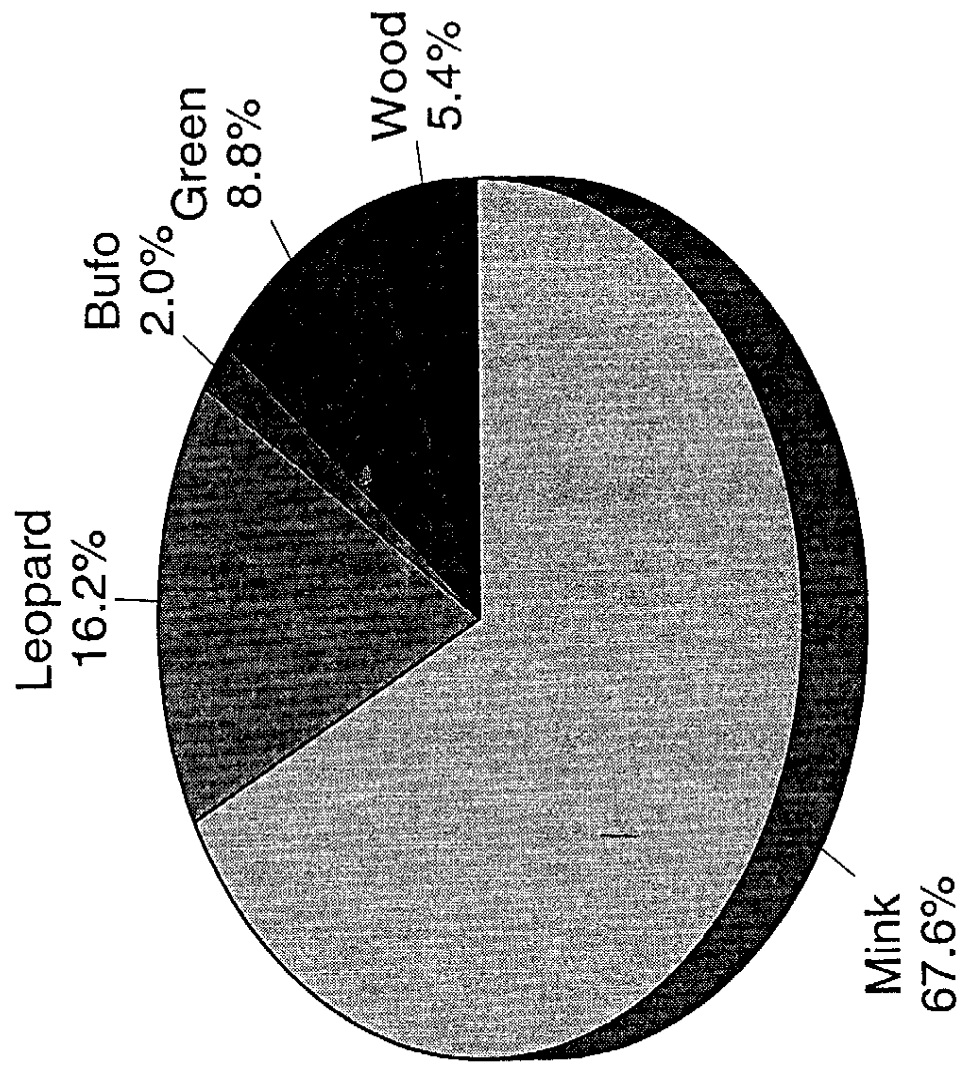


Figure 4

# Individual and Group Capture Rates

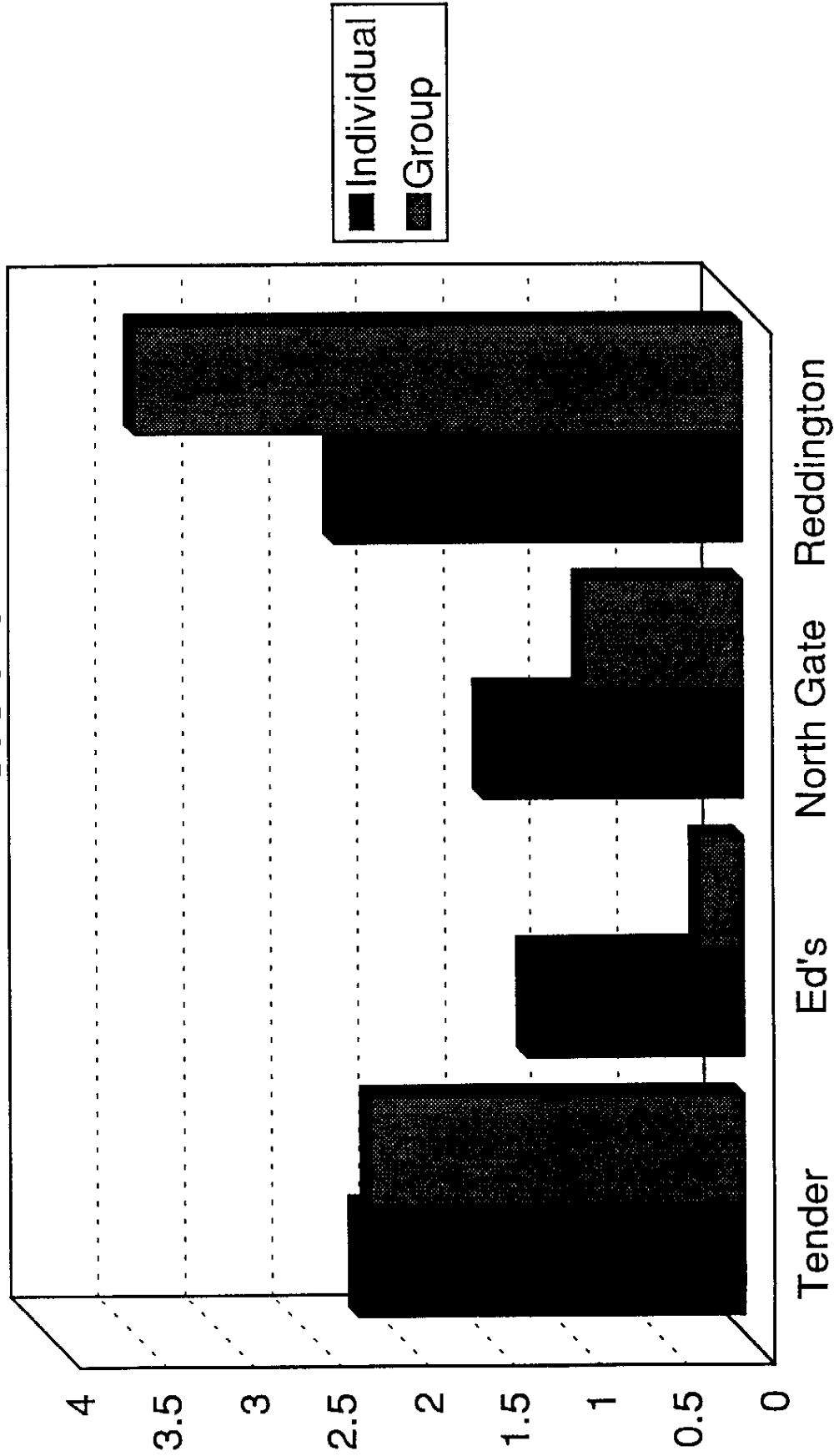
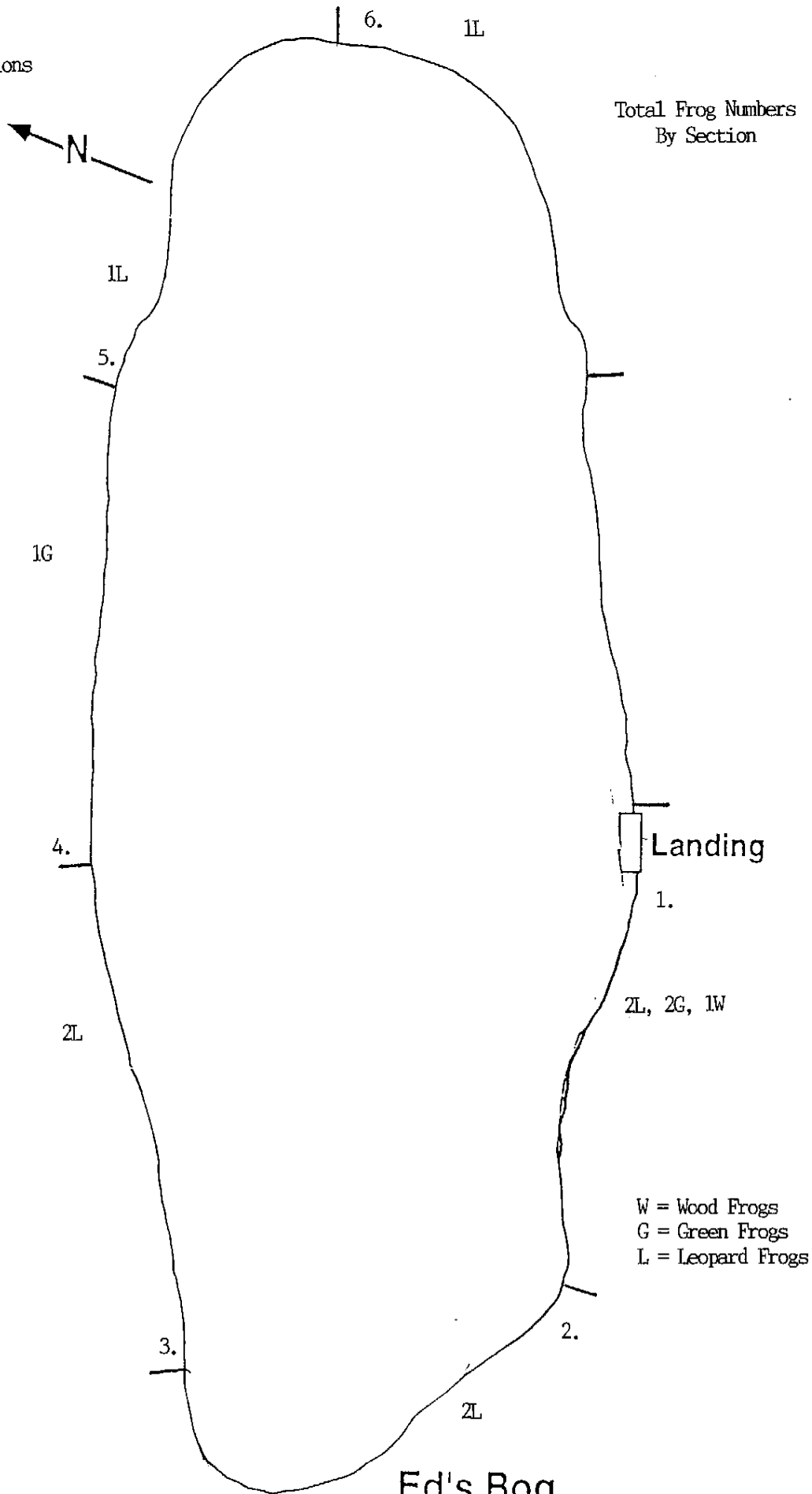


figure 5 (data in frogs/person/minutes)



Frog Populations

Figure 7



Total Frog Numbers  
By Section

1G

4.

2L

3.

2L

2L, 2G, 1W

Landing

1.

W = Wood Frogs  
G = Green Frogs  
L = Leopard Frogs

Ed's Bog

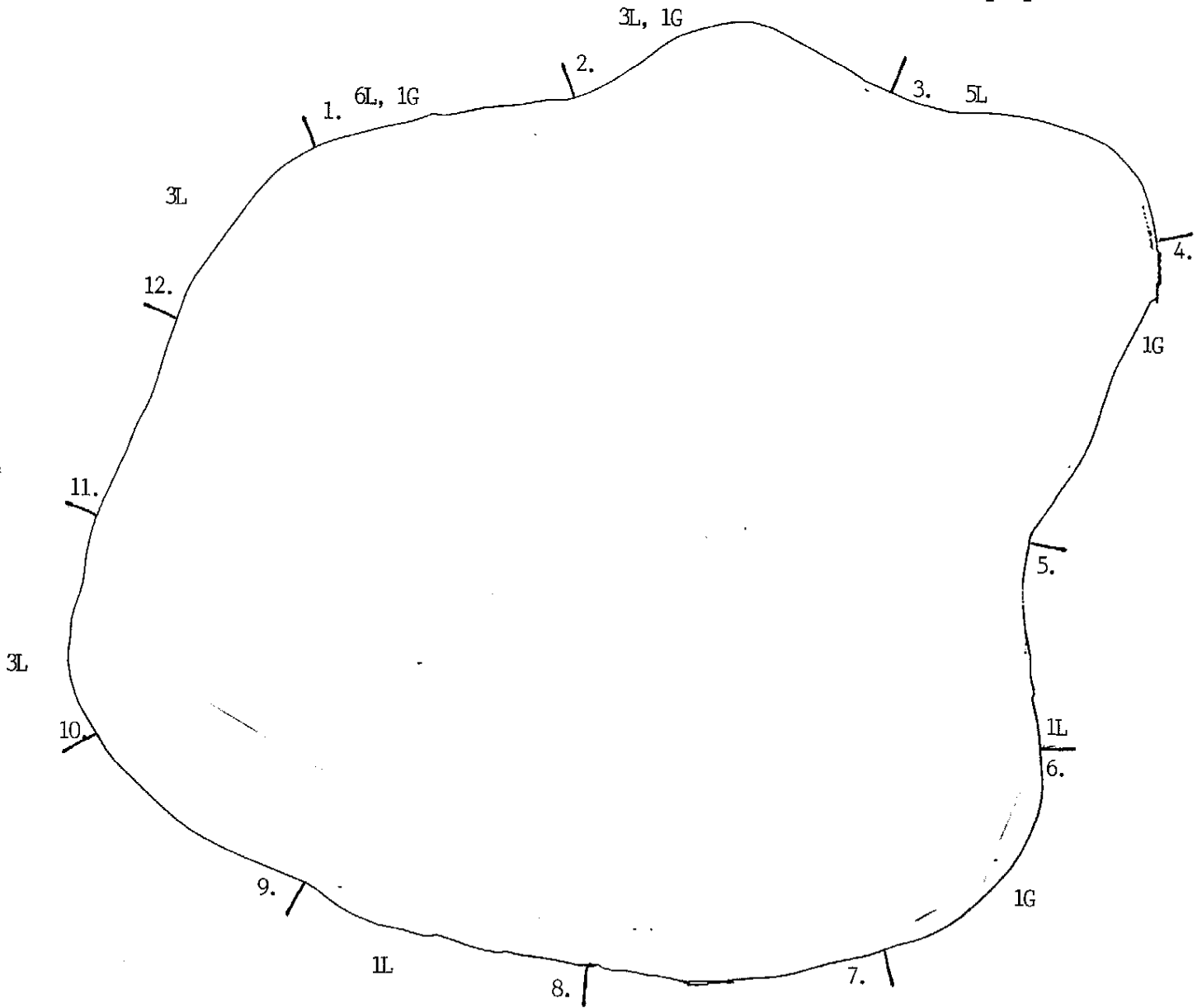
University of Notre Dame

Environmental Research Center

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# North Gate Bog

Total Frog Numbers By Section



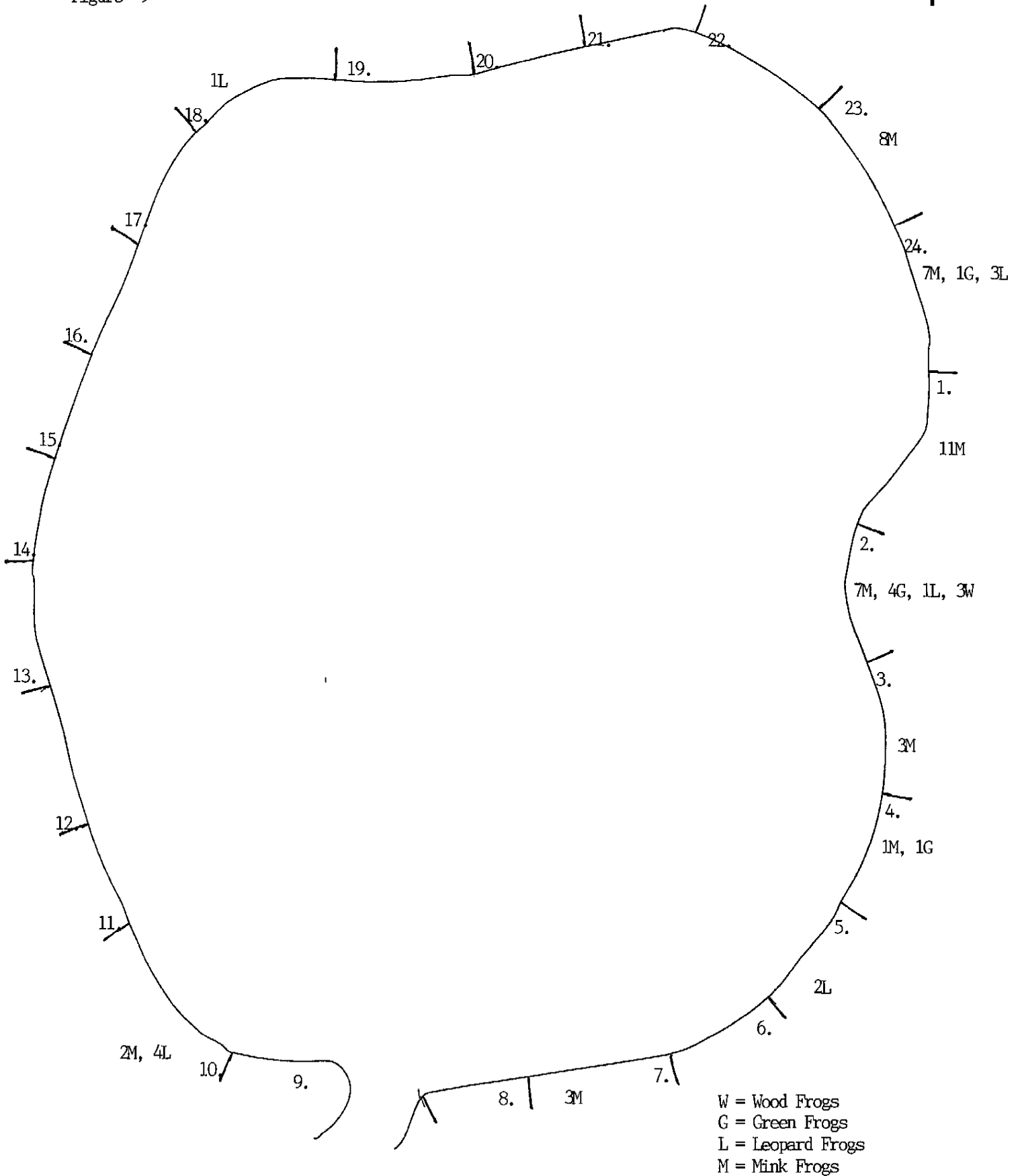
G = Green Frogs  
L = Leopard Frogs

# Reddington Lake

Total Frog Numbers By Section



Figure 9



## Frog Populations

### V. DISCUSSION

#### A. Water Chemistry

Reddington Bog data provided some interesting results that relate to last year's group study. In 1993 there was very little oxygen at the levels of 2 meters and below. (At the 2 meter depth in June, 1993 there was only 7% saturation of oxygen) (Graham 1993). This year a similar drop off in oxygen saturation at the two meter depth was recorded. Reddington's unique oxygen/temperature profile over the last two years suggests that it is merimictic.

The first water chemistry sampling days on Reddington were marred because the sample was not taken from the true bottom. Therefore, data from the May 29th bottom sample should be viewed with caution. Particularly, the phosphate concentration was likely to be low. Since these waters are believed to be merimictic, the build up of phosphate should have been much greater. A value slightly lower than the value from the second sample could be expected to account for the settling of nutrients as the summer progressed.

The pH, color, nitrates, and phosphates of each bog were consistently higher in the bottom waters than in the top waters throughout the summer. Due to lack of supplies an aluminum concentration measurement was only performed once because the chemicals were not present on May 29th.

Other interesting points included: The pH of Tender Bog in the summer of 1993 was slightly higher than pH measurements this summer. In a few cases this years data differed from previous years data. Ed's Bog has previously shown a pH of 4.2, however the average pH for this summer was 5.07 (table 3). As further evidence, Leopard Frog tadpoles found in the water would be unable to survive if the waters had a pH of 4.2. Using frogs as a bio-indicator would suggest the value of 5.07 is more accurate; certainly for this summer. Furthermore, North Gate Bog has previously shown a pH of 4.8, while the pH during the frog searches was 4.6 (table 3.). Although equipment and human error can be factors in pH measurement, these values are likely to be accurate because they were taken throughout the summer.

In addition, Ed's bog showed a slight build up of nutrients as the summer progressed and no hydrogen sulfide. North Gate Bog has a high hydrogen sulfide content as could be detected by smell. Surprisingly, both the top and the bottom chemical concentrations in North Gate Bog decreased over the summer. The other bogs had the expected build up of nutrients as the summer progressed.

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Water chemistry may also have affected the frog populations. For example, tender bog had the highest conductivity measurements and had the least amount of species diversity. Since conductivity is a measure of ion concentration, it may have a similar effect to a high aluminum measurement. It should be noted that this association is only speculative.

### B. Qualitative Frog Observations

Each bog varied slightly in its pH and also in the frog species that were present. Therefore, frogs, and likely amphibians in general, could serve as a bio indicator as to the environment that they are found in. Since the bogs had varying levels of acidity they provided the ideal way to test the effects of acid rain on frog populations in a natural setting.

In Tender Bog, the Wood frog dominated, as shown in Tables 5 and 6. Tender Bog had the most acidic waters. This parallels summer data which showed wood frogs and green frogs dominating bog waters. (Dale and Freedman 1984). Green frogs were present, but in much less numbers. Dale and Freedman studied a bog with a mean pH of 4.6. It is possible that in even more acidic waters (4.2), the wood frog has an even greater tolerance than other species. Reasons could include that the wood frog spends large amounts of time out of the water. Also, the wood frog is usually smaller than the green frog. The decreased surface area would minimize the affects of the acid water. Interestingly, 76% of the frogs were found at one end of the bog. This area had a more developed mat which could enable easier access to pools of water without having to travel to the main opening. Also, the high concentration of frogs early and late in the research period could be observations of a mating period and the resulting tadpole emergence. The pH in this section did not differ from the rest of the bog. Finally, almost all frogs seen and captured were found in areas without shrubs. While the wood frogs would escape capture by heading for the safety of the shrubs, they weren't as likely to have access to a food supply in the dense shrubs.

Both Ed's and North Gate Bog had a pH intermediate to Tender and Reddington. Both of these habitats were dominated by the Leopard frog (tables 7,8,9,10). As was shown in previous research, Leopards were found in environments where the mean pH was 4.9. Green frogs were also present at each bog, but in reduced numbers. Leopard frogs proved difficult to catch the entire study period, thus causing the irritability to measure and weigh many of them.

At Ed's Bog, late in the summer, many small recently emerged wood frogs were observed. It is possible that most of these hatchlings won't survive because they are not likely to be present in the spring, or that the bog is becoming more acidic

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and the wood frogs are beginning to get an advantage. At Ed's Bog, large numbers of Leopard tadpoles were found. These had not metamorphosed when the project ended on July 20.

Reddington Bog had the highest pH of the four bogs and also had every species of frog found elsewhere. All frogs were found in the lag that surrounded the bog (tables 11 and 12). Frogs apparently liked the warm shallow waters of the lag area. The mink frog dominated here as it did in the higher pH waters of other's research. Leopard, Green, and Wood frogs were also found throughout this area. The mink frog likely developed sooner than other species of frogs, accounting for the large numbers captured. For instance, Leopard tadpoles hadn't metamorphosed yet in Ed's bog and therefore weren't likely to have metamorphosed in Reddington. Reddington also had more developed trees on its bog mat. These are likely due to the less acidic waters of the environment.

At each of the bogs there were definite areas of the bog where frogs were likely to be found (figure 5-8). These areas shared a few traits in common. They did not have many shrubs or dense brush, they had a stable bog mat with small pools present, and they were not in constant shade. In Tender Bog the southern corner was best suited for the frogs. In Ed's Bog the south eastern corner was well populated. In North Gate Bog the northern side had the most frogs. While in Reddington, the eastern edge had the largest population. This area of Reddington also had the most extensive lag. Further research could be done comparing the micro habitats of a single bog for frog population variation.

The American toad was found at all four bogs. The Wood frog is more tolerant to a low pH than Bufo americanus (Clark 1983), as was evident at Tender Bog. Here the Wood frog thrived in and near the acidic water, while the toads were only found 100 feet away near the road. Apparently, the Wood frog excels only where other species can't. Wood frogs may be out competed for resources among the bogs with higher pH. All of the other bogs also had toads, with Reddington having the most.

It's likely that these acidic waters cause excessive ion loss which results in death of tadpoles or smaller sized adults (Freda and Dunson 1983). While the correlation between pH and frog diversity appears solid, there was a failure to find a correlation with aluminum concentration. Unfortunately, as stated earlier, the aluminum water chemistry was only done once during the summer. From the data accumulated, no patterns among the four bogs were discernable.

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### C. QUANTITATIVE

The two sampling techniques, collecting individually and with a group, provided different success rates. Tender, Ed's, and North Gate Bogs all had higher capture rates (frogs/person minutes) when frogs were captured individually rather than with the group, while the opposite was true at Reddington. The greater number of people helped to find more frogs at Reddington due to the size of its sections and the increased numbers of frogs present (figure 5). The results of Tender, Ed's, and North Gate point to a tentative conclusion that a single individual could cover the area of these bogs accurately and find all the frogs that were present, especially because certain areas of the bogs had most if not all of the frogs.

A total frog population could not be determined as tagging or toe clipping would be necessary. In Tender Bog, 92.6% of the frogs were Wood frogs (figure 1). This is not surprising because the wood frog is known to survive well in acidic waters, like Tender Bog. Finally, it was interesting that 76% of the frogs counted were located in sections 11 and 12. These sections apparently were best suited to the frogs. While the pH here was the same as in the rest of the bog, the lack of shrubs must have been a factor in this high frog density.

In Ed's Bog, 69.2% of the frogs were Leopard frogs (figure 2). This bog had the lowest total number of frogs, determined mostly through observation. Leopard frogs would likely be more dominant once the observed tadpoles emerged.

In North Gate Bog 79.3% of the frogs were Leopard frogs (figure 3).

Reddington Bog, with the highest pH of the four, had a diversity of frog species. Mink frogs had a slight dominance (67%) (figure 4), but other observations provide evidence that this number may be high. The Mink frog apparently can only survive in waters above a certain pH, because it was not found in any of the lower pH bogs. The census, through calculations relating the entire bog, pointed to 100 frogs spread across the bog. Once again it is likely that this number is low.

A good summary of pH and aluminum measurements combined with a total number of frogs captured from the summer can be seen on table 13. It is important to note that the numbers of frogs is a summer total and not the accurate censusing number. Interestingly, the wood frog excelled in low pH, the mink and leopard in higher pH, and the green was found in all pH.

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### VI. CONCLUSION

This project has completed the necessary background research for a project relating pH to frog size and species diversity. Four bogs with different pH values had definite differences in species. Apparently the aluminum concentrations were too low to show a correlation with species diversity. Furthermore, certain areas of each bog were more likely to have frogs present on any given day. Each of these areas among the four bogs shared similar characteristics. The next step is to take this project into the lab for future work, raising tadpoles in a laboratory environment. Leopard, Mink, Wood, and Green frogs, in addition to the American toad, should be raised in different pH waters. There is very likely a certain pH value below which a species could not survive accompanied with different survival rates. Another interesting study could be comparing the populations of micro habitats on a single bog.

It would be interesting to see the species diversity among these same bogs in five or ten years. A change in water chemistry, combined with a change in species diversity, would help show how frogs are a bioindicator and how acid rain is affecting the environment of the world today.

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