2700 · DNR · 327158-B

FINAL REPORT

December 1, 1979

The Relationship of Amphibians and Reptiles to Peatland Habitats in Minnesota

Attention: Peat Program
Minerals Division
Minnesota Department of Natural Resources
345 Centennial Office Building
St. Paul, MN 55155

Principal Investigator: Philip J. Regal

Submitted by: Daryl R. Karns
Project Research Assistant
Department of Ecology and Behavioral Biology
Bell Museum of Natural History
10 Church Street S.E.
University of Minnesota
Minneapolis, MN 55455

Table of Contents

1.0 INTRODUCTION

The overall objectives of the amphibians and reptiles peatland research program, as stated in the original proposal, have remained essentially the same over the past two years. In that proposal three main questions were posed:

1) What species of amphibians and reptiles are found in the Minnesotan peatlands studied?

2) The peatlands studied consist of a heterogeneous assemblage of habitat types. Which species utilize these various habitats and what is the nature of this utilization?

3) What are the key ecological factors controlling the patterns of species distribution and habitat utilization found in the peatlands studied?

These three questions have provided the framework for the research program undertaken. They additionally will serve as the basis for the organization of this report. The research of the past two years has provided the preliminary answers to these questions. As always it must be stressed that only a small portion of the vast Minnesotan peatlands was studied and for a relatively short period of time. Hence, any generalization of these findings to other geographic areas must be done with caution.

The two field seasons had different overall goals. The 1978 season was planned as a general survey of the herpetofauna of major peatland habitat types found in central and southern Koochiching County and in western Beltrami County. The 1979 season was an intensive study of one particular peatland area, Porter Ridge Bog, in central Koochiching County. The results of the 1978 season were presented in detail in Progress Report No. 5, January 1979. Therefore the Methods, Results, and Habitat Analysis Appendix of this report will deal almost exclusively with the findings of the 1979 field season. The Discussion and Summary section synthesizes the data gathered from both years. This plan was adopted to avoid making this final report unwieldy and overly redundant. Progress Report No. 5 should be thought of as the companion volume to this paper and will be referred to frequently.

The toxicity of bog water to amphibian embryos and larvae developed into a major line of investigation as the study progressed. Most of the work on this subject was done in 1979 in response to results of preliminary observations and experiments the season before; a significant portion of this report deals with those findings. Bog water toxicity was found to be an important factor affecting amphibian peatland utilization in the areas studied. In addition, the results of this investigation have important implications for organisms other than amphibians in peatland areas.

The peatlands studied have proven to be a fascinating ecological theater in which to study amphibians and reptiles. The fact that relatively little work in animal ecology has been done in such areas in the United States makes the work done by the various research groups of special value and importance.

Amphibians and reptiles are particularly interesting to study in the ecological setting of the peatlands. They are relatively small and ectothermic (cold-blooded). This means they are true residents of an area and track the environment very closely. The response of these animals to the unique environmental conditions of the peatlands has proven to be a dominant theme of this study.

2.0 METHODS

2.1. General Information

2.1.1. <u>Study area</u>. The 1978 field season consisted of a general herpetofaunal survey of peatland habitat types in central and southern

Koochiching County and in western Beltrami County (see Progress Report No. 5 Sect. 2.1.1. and Appendix for details). The 1979 field season consisted of an intensive study of one fairly restricted geographic area, the Porter Ridge Bog, located seven miles south of Big Falls in central Koochiching County. A general description of the area, maps, vegetational analysis, and climatic data for this area are presented in the Appendix.

2.1.2. Duration of field research program. The 1978 and 1979 field seasons lasted from April to mid-October each year. This 6½ month period covers the entire period of herpetofaunal activity in northern Minnesota.

2.1.3. Personnel. In 1978 field work was conducted by Daryl R. Karns, project research assistant. A volunteer field assistant, Kevin Dickey, was with the project for three months (April-June). In 1979 field work was conducted by D. R. Karns alone. Dr. Philip Regal was the project advisor. Project personnel were housed at the Big Falls Forestry Station during both field seasons.

2.2. Collecting Techniques

Field survey techniques used during the 1979 field season were basically the same as those employed in 1978 (see Progress Report No. 5, Sect. 2.2). However, a few additional comments are pertinent concerning details of the trapping fence techniques used in 1979.

2.2.1. Trapping fences. A series of 13 trapping fences was employed at the Porter Ridge area: two on the central portion of the ridge, four at ridge/fen interfaces, three on the bog side of bog drains, and four in a raised bog. See the Appendix for details of location. At sites where a sharp environmental discontinuity was apparent (e.g. bog drain or ridge/fen) one fence set parallel to the contrasting habitats was employed to pick up movement between the two habitat types. At sites where no discontinuity was apparent (e.g. central ridge or raised bog) two fences set perpendicular to each other were employed.

In 1978 all amphibians and reptiles collected were kept and preserved. In 1979 all animals collected were toe clipped, measured, sexed (if possible), and released on the opposite side of the fence on which they had been captured. Toe clipping allowed identification of individuals previously caught. Animals were occasionally removed for experimental purposes.

2.3. Water Chemistry

2.3.1. Sampling techniques. Water samples were collected at least once a month at selected sites. pH values were taken throughout the field season (April-October). Calcium and conductivity were additionally measured from April to early July when breeding, egg development, and larval growth were occurring.

Water samples were collected in 2-ounce polyethylene bottles. All bottles were acid and distilled water rinsed in the lab and rinsed again with water from the site in the field. Three samples were taken at any given site. Samples were usually taken from standing water. Trenches were occasionally dug at dry sites and water was collected from these.

2.3.2. pH (index of hydrogen ions, measure of acidity). pH was measured *in situ* or measured in the lab from bottled samples within 24 hours. Tests showed no appreciable difference between these two procedures. A radiometer PHM29B portable pH meter with combined electrode was used.

2.3.3. Specific conductivity (index of total ionic concentration). This parameter was measured with a platinum electrode. Water samples were stored at $\approx 3.5^{\circ}C$ and processed at the University of Minnesota at the earliest possible date. All conductivity data were standardized at $20^{\circ}C$, and a correction factor was applied to eliminate the effect of hydrogen ions at different levels of acidity (cf. Sjörs 1950).

2.3.4. Calcium (indicator of trophic status (nutrient richness) of a site). Calcium was measured with a Beckman Atomic Absorption Analyzer. Water samples were stored at 3.5°C and processed at the University of Minnesota at the earliest possible date.

2.4. Habitat Analysis

The habitat analysis for the 1979 season at Porter Ridge Bog is summarized in the Appendix. See Progress Report No. 5, Appendix for the 1978 season habitat analysis.

2.4.1. Vegetation analysis. Relevés and brief habitat descriptions of trapping fence sites and other important observational sites were made at the Porter Ridge Bog. Methods are described in the Appendix.

2.4.2. Microclimate. Temperature stations were set up at a number of sites. These consisted of covered weather boxes set at chest and/or ground level. The boxes contained max/min thermometers. They were checked and reset every time the site was visited. Stations were set so as to obtain comparative data between bog and ridge habitats. In addition substrate temperatures were taken at selected trapping sites each time that site was checked for captures. These were taken in the sun and shade to provide an indication of the thermal variability of the habitat. Max/min thermometers were also used to obtain information on the temperature fluctuations of the water at known amphibian breeding sites.

2.4.3. Climate. Data on daily max/min temperature and rainfall collected at the Big Falls Forestry Station were used to provide an overview of the weather in the Big Falls area. Data were collected by John Lumpio, Forestry Division technician.

2.5. Miscellaneous Habitat Data

2.5.1. Insect survey. A very preliminary attempt was made to determine if differences in insect populations occurred between bog and ridge sites at Porter Ridge Bog. In August, 6" x 24" boards coated with sticky "Tree Tanglefoot" insect trapping resin were placed at one bog and one ridge site. Four boards were positioned at substrate level at each site and left for eight days. Insects attempting to crawl across the boards were trapped and later identified and counted.

2.5.2. Other. A variety of information was collected incidental to the planned research program. In particular many small mammals were caught in the trapping fences. These animals were collected and turned over to Gerda Nordquist of the small mammals project.

2.6. Experimental Procedures

2.6.1. Bog water toxicity experiments. The relationship between peatland water chemistry and amphibian biology was experimentally investigated in the lab. Field experiments and observations were also performed. The effects of bog water on the three main stages of the amphibian life cycle were investigated: egg, aquatic larva (tadpole), and adult. Effects were measured in terms of fertilization, egg hatching success, larval survivorship, and adult tolerance. Preliminary experiments (see Progress Report No. 5, Sect. 3.3.4.) had indicated the toxic effect of bog water on amphibian eggs and larvae.

IMPORTANT: Definition of bog water

There is a great deal of variability in water quality among peatland habitats. I will use the term bog water to indicate water from ombrotrophic peatland sites showing the following characteristics: (1) low pH (<4.5), (2) low specific conductivity (<15μMhos), (3) low calcium content (around 1ppm), and (4) highly colored (high in humic substance content).

Fertilization. Breeding pairs of the Wood Frog and American Toad were brought into the lab and placed in containers of bog water or well water. These pairs were left alone and allowed to breed. Egg masses were examined for signs of fertilization. Sperm obtained from Wood Frog testes was examined in bog water and "normal" water solutions.

Egg hatching success. Freshly laid eggs were obtained from the field or from pairs mated in the lab. Egg masses were carefully teased apart and small batches of eggs of approximately equal number placed in the desired treatments. As many crosses (i.e. egg masses) were tested in a given treatment series as logistical feasibility and availability of eggs allowed. 16-ounce glass jars filled with 300 ml of test solution were used as test chambers.

The number of eggs in a test jar could influence water quality if overcrowded; preliminary experiments revealed the appropriate number of eggs per jar for a given species. pH was used as the indicator of water quality in the test jars and was monitored regularly throughout the test period. Water was changed in the test jars every day during the test period to maintain the desired treatment effect and reduce the influence of the eggs on the water quality of the test jar. Unless otherwise stated the temperature at which the tests were run was $\approx 15.5^{\circ}C$.

Dilution test series were being used; hence it was desirable to have a standard diluting medium. Reconstituted fresh water was prepared from distilled water and reagent-grade chemicals by following the U.S. government guidelines for reconstituted soft fresh water (Stephan 1975). This medium was also used as a control medium. Preliminary tests indicated it was an excellent medium for development and hatching of amphibian eggs.

Tests were scored by counting the number of live larvae and unhatched eggs in a test chamber after it was apparent that no further hatching would occur. An additional criterion was used in scoring the unhatched eggs. The egg was scored as "coil" if it contained an advanced, well-developed embryo ($\geq$ Stage 18 of Gosner 1960) that apparently was unable to hatch. Notes were made of any abnormalities observed.

The following are brief descriptions of the different test treatment series:

1) Bog water vs. control water. All six species for which eggs were available (Wood Frog, American Toad, N. Spring Peeper, N. Leopard Frog, Chorus Frog, and Blue-spotted Salamander) were tested to determine if bog water did have a deleterious effect on hatching success compared to the favorable hatching medium of the control.

2) Bog water dilution series. Wood Frog and American Toad eggs were subjected to a series of treatments of bog water diluted with reconstituted control water. The dilutions were as follows: 100% bog water, 90%, 80%, 70%, 60%, 40%, 20%, and control. This was done to define the potency of bog water toxicity.

3) Acidity gradient series. Wood Frog and American Toad eggs were subjected to a series of H_2SO_4 (sulfuric acid) control water solutions of decreasing acidity (pH=3.0, 3.5, 4.0, 4.5, 5.0, 6.0, and control (pH 7.5)). H_2SO_4 was used as the acid because it is the major acid found in natural bog water (Gorham, personal communication). This series was performed to determine if acidity alone would produce effects similar to that of bog water and at what levels.

4) Bog water and buffer. Wood Frog, American Toad, and N. Spring Peeper eggs were subjected to bog water that had been treated with buffering agents (either $CaCO_3$ or NaOH) to artificially increase pH. Bog water and control treatments were also run with each cross for comparison. This series was performed to determine if bog water could be transformed into a satisfactory breeding medium by changing pH alone.

5) Temperature. Wood Frog and American Toad eggs were subjected to bog water and control water treatments at two different temperatures. One

bog and control water series was kept at 3.5^{o}C, the other at 15.5^{o}C. This series was performed to determine if temperature could significantly change the toxic effect of bog water.

6) Microhabitat variation in water quality. It was noted that water quality varied over very short distances (<100m) in nature. Water was collected from the ridge side and the bog side at one site along the Porter Ridge bog drain (see Appendix, Wide Bog Drain, Habitat Description E) and used as test mediums. A control medium was also run. Wood Frog eggs were subjected to the three solutions. This series was performed to determine what effect variations in water quality over very short distances could have on hatching success.

7) Field experiments and observations. Eggs of several species (especially the Wood Frog) were carefully removed from egg masses in the field at sites of various water qualities and examined in the lab to determine if effects similar to those seen in the lab were in fact occurring in nature.

Larval survivorship. Larvae of six species (Wood Frog, American Toad, Chorus Frog, N. Spring Peeper, N. Leopard Frog, Blue-spotted Salamander) were subjected to a series of treatments of bog water diluted with reconstituted water. The dilutions were as follows: 100% bog water, 90%, 80%, 70%, 60%, 40%, 20%, and control. All larvae used were newly hatched (Stage 24-26). Test chambers for this series were one-gallon glass jars filled with approximately three liters of solution. This volume of water maintained original pH levels for the entire test period and was not changed. pH was monitored throughout the test period. A standard toxicity test format was followed (Stephan 1975). Test jars were checked for dead larvae at 12, 24, 36, 48, 72, and 96 hours after test initiation; dead larvae were removed. This series was performed to determine if bog water was toxic to larvae and at what levels of concentration.

Field observations on larvae. Larval surveys were performed at sites of various qualities. A plastic tray was plunged into the water and the amphibian larvae, aquatic insects, etc. caught on each plunge were retained. A set number of plunges was done at each site to provide quantitative comparison. Surveys were done in June and July. These surveys were done to check under field conditions the results of the lab larval experiments.

Larval rearing experiments. Only one species, the Wood Frog, exhibited tolerance to bog water in hatching success and larval survivorship. Sixty Wood Frog larvae hatched in bog water were retained and kept in bog water on a bog vetetation diet to determine if successful development and growth through metamorphosis was possible. Larvae were also reared in control solutions on nonbog vegetation diets.

Adult survivorship. The ability of adult Wood Frogs and American Toads to tolerate exposure to bog water was tested. Two test treatments were used: (1) bog water immersion- test animal placed in a 16-ounce glass jar; jar filled with bog water to approximately eye level; animal was immersed in the water yet could sit comfortably; (2) well water immersion- same method as above with well water.

Water in the test jars was changed daily. All containers were checked twice daily for dead animals. The test was allowed to run 60 days. Animals of various sizes and of both sex were used and these were distributed among the test treatments in as equitable a fashion as possible.

2.6.2. Overwintering experiments. The physiological ability of Wood Frogs and American Toads to tolerate prolonged exposure to water-saturated conditions was investigated. This tolerance has important implications for overwintering in the wet soils of peatland habitats.

Hydration stress test. This test compared the abilities of the two dominant amphibian peatland species to tolerate immersion in distilled water. Two treatments were employed with each species: (1) control-animal placed in a 16-ounce jar with $\approx$1/4" tap water; water changed every other day; (2) distilled water-animal placed in a 16-ounce jar; jar filled with distilled water to approximately eye level; animal could sit comfortably and remain immersed in the water; water changed daily. Thirty specimens of each species were tested in both treatments. Animals were separated as equitably as possible in the two treatments by size and sex.

The test was allowed to run three months. All jars were checked daily. The day on which an animal was found dead was recorded. All dead animals were kept and preserved. From this information a comparison of survival times between treatments and species was calculated. All animals used in the experiment came from Porter Ridge Bog. They were caught during August and September.

Coldroom experiment. Five-gallon plastic buckets of water-saturated peat soil and sandy upland ridge soil from the Porter Ridge area were collected in September. Wood Frogs and American Toads from the area were also obtained. The buckets were placed in a large walk-in coldroom at the Bell Museum with a temperature of 4.5^{o}C. There were two wet peat soil and two sand soil buckets for each species. Seven to eight frogs or toads were placed in each bucket. Wire mesh covers were fitted in the buckets flush with the peat or sand surface. The covers insure that animals are kept in the soil to be tested and cannot escape. The buckets are checked at two week intervals and dead animals recorded and removed. The experiment is still in progress at this time and will be run for a total of five months.

3.0 RESULTS

3.1. The Porter Ridge Bog Herpetofauna

Before presenting the results obtained from the trapping fence survey several points must be stressed: (1) The 1979 field season was a detailed investigation of one site, the Porter Ridge Bog, and involves one 6-1/2 month trapping season. (2) The trapping fence technique was found to be the most reliable and productive available. It is, however, a biased sampling method that is not effective at capturing larger animals (e.g. adult turtles or larger snakes) or semiarboreal forms (e.g. Gray Tree Frog).

(3) In the construction of the habitat utilization tables (Tables 2-4), recaptured animals, identified by toe clipping, were ignored. Hence, the number of individuals caught represents an index of movement through that area.

3.1.1. Species composition. In 1979,1380 amphibians and 4 reptiles were caught at the 13 drift fences in the Porter Ridge area. No new species were collected. Table 1 presents the list of species found in 1978 and 1979 in central and southern Koochiching County and western Beltrami County.

The taxonomic status of several species on that list was clarified. The Gray Tree Frog (Hyla versicolor) was positively identified by sound spectrograph analysis of breeding calls. Hyla chrysoscelis is a closely related species. It is so morphologically similar to H. versicolor that physical characteristics cannot be used to distinguish the two forms. However, breeding call characteristics do differ. Tape recordings were made at several sites and later analyzed.

The Blue-spotted Salamander (Ambystoma laterale) was positively identified by measurement of red blood cells. There is a closely related species (Ambystoma tremblayi) that is morphologically difficult to distinguish from A. laterale. Red blood cell size has been shown to be an effective means of identification (Downs 1978).

The subspecific status of the Chrous Frog (Pseudacris triseriata) remains unclear. Northern Minnesota is on the border of the hybrid zone between the Western and Boreal Chorus Frogs (Conant 1975), and specimens from the study area cannot be clearly categorized.

Table 1. Checklist of the amphibians and reptiles of the peatlands; central and southern Koochiching and western Beltrami counties, Minnesota.[1]

AMPHIBIANS	
Frogs and Toads	
Family Hylidae (Treefrogs)	
*Hyla c. crucifer**,	Northern Spring Peeper
*Hyla versicolor**	Gray Tree Frog
Pseudacris triseriata[2]	Chorus Frog
Family Ranidae (True Frogs)	
Rana sylvatica	Wood Frog
*Rana pipiens**	Northern Leopard Frog
Family Bufonidae (Toads)	
*Bufo a. americanus**	American Toad
Salamanders	
Family Ambystomatidae (Mole Salamanders)	
*Ambystoma laterale**	Blue-spotted Salamander
Family Necturidae (Giant Salamanders)	
Necturus m. maculosus[3]	Mudpuppy
REPTILES	
Snakes	
Family Colubridae (Colubrids)	
*Thamnophis s. sirtalis**	Eastern Garter Snake
*Storeria o. occipitomaculata**	Northern Red-bellied Snake
Turtles	
Family Emydidae (Water Turtles)	
Chrysemys picta belli	Western Painted Turtle
Family Chelydridae (Snapping Turtles)	
Chelydra s. serpentina[3]	Common Snapping Turtle

[1] This checklist was compiled from specimens collected and observations made during the 1978 and 1979 field seasons. Specimens collected are now deposited in the Bell Museum of Natural History, University of Minnesota.

[2] Taxonomic questions about the subspecific status of this species remain (see Sect. 3.1.1.).

[3] These species were not actually collected but available evidence indicates their presence in the area (Conant 1975; Breckenridge 1970; and personal communication with local residents).

* Asterisk indicates that the species was found at the Porter Ridge Bog intensive study site.

3.1.2. Habitat utilization. Tables 2-4 present the analysis of the trapping fence data by species, site, and habitat type. Tables 2 and 3 present data for each trapping site. The data for sites with pairs of fences (e.g. Ridge I & II) has been combined. Note that Table 2 consists of sites at the western end of Porter Ridge. Table 3 sites are located to the east and form a transect that progresses from the center of Porter Ridge into the adjacent raised bog (see Appendix, Fig. 2A). This transect is of particular interest in bog/ridge comparisons. Table 4 summarizes the data from the 13 fence sites by separation into the major habitat types sampled.

All tables are based on trapping results from June to October, 1979. Because of environmental and logistical factors, fences went into operation at different dates. By June, all fences were functioning. For valid comparison between sites it is important that the trapping periods be essentially the same.

The most important statistic presented in these tables is the number/caught/fence/day. The total number caught is divided by the number of days fences were open and corrected for differences in the number of fences used. This statistic allows valid comparison between sites in spite of differences in trapping effort.

The results of these tables can be profitably considered by examining habitat type and species differences:

3.1.3. Habitat differences in species utilization. Ridge and ridge/fen. These habitats were the sites richest in both species diversity and relative abundance. Six species of amphibians and two species of snakes were caught in ridge-related habitats. Overall ridge/fen was the most productive habitat producing 3.06 animals/fence/day compared to 1.62 for the two central ridge fences.

Bog drain. The three bog drain sites were intermediate in species diversity and relative abundance. Overall 0.77 animals/fence/day were

Table 2. Trapping fence site data analysis I: June-October 1979. Data by species and by trapping fence site are shown for the five fence sites at the western end of the Porter Ridge Bog study area. See Sect. 3.1.2. for details.

Species / Trapping Site	Ridge/Fen I (71)[3]	Ridge/Fen II (71)	Ridge/Fen III (71)	Bog Drain I (71)	Bog Drain II (71)	Total (Each Species; All Sites)
Rana sylvatica (Wood Frog)						
No. Caught[1]	87 (33.7)	174 (60.8)	108 (76.6)	6 (22.2)	18 (32.7)	393 (51.2)
No. Caught/ Fence/Day[2]	1.23	2.5	0.96	0.08	0.25	1.11
Bufo americanus (American Toad)						
No. Caught	34 (13.2)	29 (10.1)	11 (7.8)	17 (63.0)	30 (54.5)	121 (15.8)
No. Caught/ Fence/Day	0.48	0.41	0.15	0.24	0.42	0.34
Pseudacris triseriata (Chorus Frog)						
No. Caught	73 (28.3)	7 (2.4)	13 (9.2)	0 (0.0)	0 (0.0)	93 (12.1)
No. Caught/ Fence/Day	1.03	0.1	0.18	0.0	0.0	0.26
Ambystoma laterale Blue-spotted Salamander						
No. Caught	62 (24.0)	58 (20.3)	8 (5.7)	4 (14.8)	6 (10.9)	138 (18.0)
No. Caught/ Fence/Day	0.87	0.82	0.1	0.06	0.05	0.39
Hyla c. crucifer N. Spring Peeper						
No. Caught	2 (0.8)	18 (6.3)	1 (0.7)	0 (0.0)	1 (1.8)	22 (2.9)
No. Caught/ Fence/Day	0.03	0.3	0.01	0.0	0.01	0.06
Total (All species; each site)						
No. Caught	258 (33.6)	286 (37.3)	141 (18.4)	27 (3.5)	55 (7.2)	767 (100.0)
No. Caught/ Fence/Day	3.6	4.01	1.99	0.38	0.77	2.16

[1]The No. Caught is the entire number of animals caught from June-October for a given species at a particular site. The number in parentheses below it is the No. Caught expressed as a percentage of the total number of animals caught at that site.

[2]The No. Caught/Fence/Day is the total number of animals caught from June to October divided by the total number of days the fence was open during that period.

[3]This number is the total number of days the trapping fence(s) was open from June-Oct.

Table 3. Trapping fence site data analysis II: June-October 1979. Data by species and by trapping fence site are shown for the eight fence sites which form the bog/ridge transect at the Porter Ridge Bog study area. Note that for some sites the results from two adjacent fences have been combined (Ridge I & II, Raised Bog I & II, and Raised Bog III & IV). See Sect. 3.1.2. for details.

Species / Trapping Site	Ridge I & II (140)[3]	Ridge/Fen IV (73)	Bog Drain III (72)	Raised Bog I (139)	Raised Bog II (139)	Total (Each Species; All Sites)
<u>Rana sylvatica</u> (Wood Frog)						
No. Caught[1]	79	84	16	25	31	235
	(34.8)	(44.2)	(19.5)	(37.9)	(64.6)	(38.3)
No. Caught/[2] Fence/Day	0.56	1.15	0.22	0.18	0.22	0.42
<u>Bufo americanus</u> (American Toad)						
No. Caught	53	42	52	36	15	198
	(23.3)	(22.1)	(63.4)	(54.5)	(31.3)	(32.3)
No. Caught/ Fence/Day	0.38	0.58	0.72	0.26	0.11	0.35
<u>Pseudacris triseriata</u> (Chorus Frog)						
No. Caught	22	20	2	0	0	44
	(9.7)	(10.5)	(2.4)	(0.0)	(0.0)	(7.2)
No. Caught/ Fence/Day	0.16	0.27	0.03	0.0	0.0	0.08
<u>Ambystoma laterale</u> Blue-Spotted Salamander						
No. Caught	58	21	12	5	2	98
	(25.6)	(11.1)	(14.6)	(7.6)	(4.2)	(16.0)
No. Caught/ Fence/Day	0.41	0.29	0.17	0.04	0.01	0.17
<u>Hyla c. crucifer</u> N. Spring Peeper						
No. Caught	15	23	0	0	0	38
	(6.6)	(12.1)	(0.0)	(0.0)	(0.0)	(6.2)
No. Caught/ Fence/Day	0.11	0.32	0.0	0.0	0.0	0.07
TOTAL (All Species; Each Site)						
No. Caught	227	190	82	66	48	613
	(37.0)	(31.0)	(13.4)	(10.8)	(7.8)	(100.0)
No. Caught/ Fence/Day	1.62	2.60	1.14	0.47	0.35	1.09

[1,2,3]See legend, Table 2, for explanation.

Table 4. Summary of trapping fence site data by habitat type: June-October 1979. The locations of the trapping fence sites were classified by general habitat type and the data from those sites combined for a given habitat. At the Porter Ridge Bog study area four general habitat types were recognized: Ridge, Ridge/Fen, Bog Drain and Raised Bog. See Sect. 3.1.2. for details.

Species / Habitat Types	Ridge (2 trapping fences) (140)[3]	Ridge/Fen (4 trapping fences) (286)	Bog Drain (3 trapping fences) (214)	Raised Bog (4 trapping fences) (278)	Total (Each species; All sites)
Rana sylvatica Wood Frog					
No. Caught[1]	79 (34.8)	453 (51.8)	40 (24.4)	56 (49.1)	628 (45.5)
No. Caught/ Fence/Day[2]	0.56	1.58	0.19	0.20	0.68
Bufo americanus American Toad					
No. Caught	53 (23.3)	116 (13.3)	99 (60.4)	51 (44.7)	319 (23.1)
No. Caught/ Fence/Day	0.38	0.41	0.46	0.18	0.35
Pseudacris triseriata (Chorus Frog)					
No. Caught	22 (9.7)	113 (12.9)	2 (1.2)	0 (0.0)	137 (9.9)
No. Caught/ Fence/Day	0.16	0.40	0.01	0.0	0.15
Ambystoma laterale Blue-spotted Salamander					
No. Caught	58 (25.6)	149 (17.0)	22 (13.4)	7 (6.1)	236 (17.1)
No. Caught/ Fence/Day	0.41	0.52	0.10	0.03	0.26
Hyla c. crucifer N. Spring Peeper					
No. Caught	15 (6.6)	44 (5.0)	1 (0.6)	0 (0.0)	60 (4.4)
No. Caught/ Fence/Day	0.11	.15	0.001	0.0	0.07
TOTAL (All species; each site)					
No. Caught	227 (16.4)	875 (63.4)	164 (11.9)	114 (8.3)	1380 (100.0)
No. Caught/ Fence/Day	1.62	3.06	0.77	0.41	1.5

[1,2,3] See legend, Table 2, for explanation.

caught. Four species of amphibians and one snake were caught.

Raised bog. This habitat was lowest in species diversity and relative abundance. Three species of amphibians and no reptiles were caught. Overall 0.41 animals/fence/day were caught. The number caught was less at the site farthest from the ridge than at the intermediate raised bog site (0.35 vs. 0.47 animals/fence/day).

There are important bog/ridge differences. Ridge/fen sites produced 5 more species and 7½ times as many animals on a fence/day basis. There is a steady decline in relative abundance as one moves away from the ridge into the bog.

3.1.4. Species differences in habitat utilization. In the following summary each species is characterized as follows: (1) whether the trapping fence was effective; (2) general life style (e.g. ground dwelling vs. semiarboreal); (3) breeding behavior--two categories: (a) explosive breeding (lasting a relatively short period, ≤ two weeks), (b) prolonged breeding (> two weeks); and (4) tolerance of embryos to bog water. (see Sect. 3.3). This characterization is followed by general comments about the species' importance in the peatlands herpetofaunal community.

Wood Frog (*Rana sylvatica*)-- Trapping fence effective; ground dweller; explosive breeder; limited bog water tolerance. The Wood Frog was the dominant amphibian species of the Porter Ridge Bog, comprising 45.5% of the total number of amphibians caught. It was found in relatively substantial numbers in all habitats. It was the only species whose numbers remained constant along the ridge/bog transect out into the bog. This species was observed breeding at bog water sites. The Wood Frog is the only species to show tolerance to bog water in hatching success and larval survivorship. This species seems to be the best suited for bog habitats, in general, of those studied.

American Toad (Bufo a. americanus)--Trapping fence effective; ground dwelling species; explosive breeder; bog water intolerant. The American Toad was second in importance comprising 23.1% of the total number of amphibians caught. It was notably abundant in the bog drain (60.4% of the total for that habitat). Along the ridge/bog transect it dropped off in numbers (0.26 toads/fence/day at Raised Bog I vs. 0.11 at Raised Bog II). This species was observed to breed at bog water sites.

Blue-spotted Salamander (Ambystoma laterale)--Trapping fence effective; secretive, largely subterranean species; explosive breeder; bog water intolerant. This salamander was the third in importance comprising 17.1% of the total number of amphibians caught. It was found in all habitats but was most abundant at ridge sites. Along the bog/ridge transect its numbers decreased with distance from the ridge.

Chorus Frog (Pseudacris triseriata)--Trapping fence effective; ground dweller; prolonged breeder; bog water intolerant. The Chorus Frog was fourth in importance comprising 9.9% of the total number of amphibians caught. This species was essentially restricted to ridge sites and seemed to avoid sphagnum-dominated sites almost completely. Only two specimens were caught in the bog drain and none at the raised bog sites. The Chorus Frog was not observed to breed at bog water sites in any numbers.

Northern Spring Peeper (Hyla c. crucifer)--Trapping fence effective; semiarboreal to ground dweller; prolonged breeder; bog water intolerant. This species was fifth in importance comprising 4.4% of the total number of amphibians caught. The Peeper was identical to the Chorus Frog in distribution and was restricted to ridge sites. One specimen was caught at the edge of the bog drain. None were caught at the raised bog sites. This species was observed to breed at bog water sites.

Gray Tree Frog (Hyla versicolor)--Trapping fence ineffective; semiarboreal to arboreal; prolonged breeder; bog water tolerance not known. This species was not caught in the trapping fences at Porter Ridge. It is known to breed in the area. The Gray Tree Frog is fairly large and an effective climber undoubtedly capable of escape from the trapping fence pitfall cans; its distributional status with respect to bog/ridge habitats is therefore unclear. This species was not observed to breed at bog water sites.

Northern Leopard Frog (Rana pipiens)--Trapping fence effective; ground dweller; explosive breeder; bog water intolerant. This species was not captured at all in 1979. It is, however, known to be in the area and was captured in 1978 (4 specimens) at the open fen/swamp thicket site on the north side of Porter Ridge (see Progress Report No. 5, Sect. 3.2.1.). The Leopard Frog was never found at sphagnum-dominated sites. It was associated with larger ponds, ditches, and extremely wet areas in general. This species was not observed to breed at bog water sites.

Northern Red-bellied Snake (Storeria o. occipitomaculata). Trapping fence effective for most sizes; ground dweller. Only three specimens were caught in 1979: 5/16--Ridge I; 6/7--Ridge/Fen II; 9/5--Bog Drain I. This is a small species (20-27 cm adult size) for which the traps should be effective for all but the largest adults. Hence the low number captured may reflect true abundance in the area. The 1978 season produced only eight specimens (all from upland sites). In 1979, two were from ridge sites and one from the edge of the bog. This species has been reported in sphagnum bogs (Conant 1975).

Eastern Garter Snake (Thamnophis s. sirtalis)--Trapping fence effective for smaller sizes; ground dweller. Only one specimen was caught in 1979 (Ridge I, 9/6). Observations indicate it was fairly common on Porter Ridge, and the trapping record does not reflect true abundance at all. In 1978 only two were captured; the capture of one of these at the Wisner Bog site indicates that this species does move out into sphagnum-dominated areas. This snake was the most conspicuous reptile in the areas studied.

Other--An aquatic salamander, the Mudpuppy (*Necturus m. maculosus*), is known in the general area. This species prefers lakes, ponds, and streams and was not found in the Porter Ridge area.

The Western Painted Turtle (*Chrysemys picta belli* and *Chelydra s. serpentina*) are known in the general area. They also are largely aquatic and prefer large ditches, lakes, and streams. They were not found in the Porter Ridge area.

3.1.5. Seasonal movements. The habitat and species accounts presented above provide an overview of herpetofaunal utilization patterns in the Porter Ridge area. Obviously information about the seasonal timing of movements and type of individuals making those movements is hidden in such an overview.

Amphibian life cycle movements. There are distinct movements associated with seasonal amphibian life cycle events. A generalized sequence of seasonal movements for adult amphibians runs as follows: (1) spring emergence, (2) movement to breeding areas, (3) postbreeding period dispersal, (4) summer feeding activity, (5) movement to overwintering sites in fall, and (6) overwintering and dormancy. An additional major movement involves movement of the young of the year (i.e. juvenile frogs laid as eggs in spring that had hatched, developed, and metamorphosed into fully developed frogs) away from the breeding ponds in late summer.

The results from the trapping fences indicate the direction and strength of these movements if the fences are located along movement corridors (e.g. between a breeding area and adjacent upland). For example, at Ridge/Fen III in May, 19 adult Wood Frogs were caught on the north side moving toward the adjacent fen (where breeding was occurring) and only one on the south side (indicating movement away from the breeding area). In May and June (postbreeding dispersal) the statistics were reversed and 34 were captured on the south (movement away from fen) and three on the north (movement toward fen). In August,25 recently metamorphosed Wood Frogs were caught on the south (moving away from fen); no frogs were caught moving toward the fen. The August data indicate the dispersal of the young of the year. Similar examples could be given for other species and sites.

Delay in spring emergence. As discussed in Sect. 4.2.2.,sphagnum bogs in general "thaw late and freeze early." This has important ecological implications. In the Porter Ridge area animals were caught at ridge sites as soon as the majority of snow cover disappeared. In 1979 this was about April 20. Chorusing was heard almost immediately thereafter in the fens and bog drain. Wood Frog eggs were found on April 27 in the bog drain. No amphibians were caught at the bog drain or raised bog sites until about May 20, a month later. The same delay was noted at Wisner Bog in 1978. Clearly early breeders that overwintered in the raised bog would be at a disadvantage compared to those who had overwintered on the ridge and emerged much earlier. When chorusing began at Porter Ridge there was still a 50% snow cover and largely frozen substrate at Bog Drains I & II (located at the edge of the raised bog) while there was virtually snow-free substrate and largely unfrozen soil (in the open) at Ridge/Fen II and III.

Also of interest in this respect are the toad emergence data from the bog drain sites. Toads breed somewhat later in the season (around the last two weeks of May and into June). In April, May,and June the movement data were as follows: April: zero toads caught; May 20-31: 5 toads (38.5%

of the total) caught moving toward the bog and 8 (61.5%) caught moving toward the ridge; June 1-15: 4 (8.0%) caught moving toward the bog and 50 (92.6%) caught moving toward the ridge. The data strongly suggest a dramatic emergence and movement away from the bog toward the ridge-associated breeding sites in early June. The May data suggest a few early bog emergers plus some wanderers from the nearby ridge. It seems reasonable that the reason for the sudden June "breakout" is the differential in thawing between the ridge and bog.

Bog/ridge differences in age and size class. The 1978 data from the Wisner Bog site indicated that in the early part of the season (April-June) a different class of individuals was caught at the raised bog site. They were generally small and nonreproductive. In the July-October period there was an invasion of the bog by adult-sized individuals. This influx was interpreted as a post-breeding season dispersal away from the adjacent upland. Does Porter Ridge exhibit the same pattern? Table 5 presents the Porter Ridge Bog and Wisner Bog data. The same pattern is seen at both sites in the April-June period for both the Wood Frog and American Toad. Smaller, nonreproductive individuals of both species constitute a high percentage of the animals caught (81.5-95.7%). As expected at the Porter Ridge ridge/fen sites the breakdown is exactly the opposite; adults are dominant. The data from bog drain sites show an intermediate condition.

Does an invasion of adults occur in the bog at Porter Ridge? There is no invasion of Wood Frogs. The proportion of small nonreproductive individuals to adults remains similar (85.7% vs. 91.4%) in the early and the late periods of the season. The American Toad data show a substantial increase in adult-sized toads from the April-June to the July-October period (18.5% to 70.8%). Wisner Bog data shows an increase in adult-sized animals for both species. There is a major increase in adult-sized Wood Frogs (4.3% to 43.6%) and a moderate increase in adult-sized American Toads (4.5% to 18.2%) at Wisner Bog.

Table 5. Seasonal differences in size of Wood Frogs and American Toads in several peatland habitat types. See Sect. 3.1.5. for details.

Species and Site \ Season and Size	April-June		July-October	
Wood Frog	% <40mm	% ≥40mm	% <40mm	% ≥40mm[1]
Porter Ridge (1979)				
Ridge/Fen	7.6 (20)[3]	92.4 (242)	35.9 (147)	64.1 (262)
Bog Drain	44.4 (4)	55.6 (5)	48.6 (17)	51.4 (18)
Raised Bog	85.7 (6)	14.3 (1)	91.4 (43)	8.5 (4)
Wisner Road Raised Bog (1978)	95.7 (22)	4.3 (1)	56.4 (57)	43.6 (44)
American Toad	<55mm	≥55mm	<55mm	≥55mm[2]
Porter Ridge (1979)				
Ridge Fen	47.3 (53)[3]	52.7 (59)	32.6 (30)	67.4 (62)
Bog Drain	51.5 (34)	48.5 (32)	20.5 (9)	79.5 (35)
Raised Bog	81.5 (22)	18.5 (5)	29.2 (7)	70.8 (17)
Wisner Road Raised Bog (1978)	95.5 (64)	4.5 (3)	81.8 (72)	18.2 (16)

[1]Wood Frog size. Frogs ≥ 40mm in head/body length are usually reproductive adults. Frogs <40mm are usually nonreproductive immature frogs.

[2]American Toad size. Toads ≥ 55mm in head body length are usually reproductive adults. Toads <55mm are usually nonreproductive immature toads.

[3]Number in parentheses is the actual number of frogs or toads caught of a given size at a given site.

These findings further emphasize the differences between the bog and ridge habitats. Within the two dominant peatland amphibian species there is a differential utilization of bog and upland by immature and adult age-size classes. The reasons for the differences between the two sites are not clear.

3.1.6. Insect survey. The insect trapping survey, operated for one week in August, revealed interesting differences between bog and ridge sites. At the ridge sites a mean of 166 insects was collected per trap (4 traps, range = 24-65/trap). The bog site produced a mean of only 42 per trap (4 traps, range = 113-241/trap).

The insects collected at both sites were mainly flies. This simple survey indicated a fourfold difference between the two sites.

3.2. Water Chemistry

3.2.1. General area. Analyses of water samples have shown that the peatland habitats studied were very heterogeneous with respect to water quality on both a macroscale and microscale (in terms of the relative size of the areas investigated). Our results and observations are in agreement with Heinselman's (1970) findings that water chemistry is a major factor in determining the vegetational and landscape patterns seen in peatlands. Tables 6, 7, and 8 give pH, conductivity, and calcium measurements for selected sites in the central Koochiching County area. On a broad scale three main classes are clearly discernible. Heinselman's (1970) water chemistry classification defines these as follows:

(1) Ombrotrophic waters: pH = 3.8-4.3; Ca content (ppm) = 0.5-1.6; "corrected" conductivity (μMhos) = 1.8-12.6. Examples: raised bog sites, bog drains.

(2) Weakly minerotrophic waters: pH = 5.2-6.4; Ca content (ppm) = 4.2-15.0; "corrected" conductivity = 27.0-62.0. Examples: upland (ridge)/fen border areas, tamarack swamp, swamp thicket.

Table 6. pH, calcium content, and specific conductivity of four peatland habitat types: July, 1979. See Sect. 2.3. and 3.2 for details.

Measurement Site	ph	Ca (ppm)	Corrected Conductivity 20^{o}C (μMhos)	Classification[1]
Cedar Swamp	7.0	39.0	162.1	M
Tamarack Swamp	6.3	15.0	62.0	WM
Swamp Thicket	6.1	12.0	52.9	WM
Raised Bog A	4.0	2.2	9.3	O
Raised Bog B	4.1	1.0	7.4	O
Raised Bog C	4.0	1.0	7.5	O
Raised Bog D	3.8	0.8	6.4	O

[1] M = minerotrophic site
WM = weakly minerotrophic site
O = ombrotrophic site

Table 7. pH, calcium content, and specific conductivity of selected sites in the Porter Ridge Bog Area: June and July, 1979. See Sect. 2.3. and 3.2. for details. See Appendix for location and description of sites.

Measurement Site		pH		Ca (ppm)		Corrected Conductivity 20°C (µMhos)		Classification[1]
		June	July	June	July	June	July	
Bog Drain		4.1	4.1	1.2	1.0	10.6	11.7	0
Wide Bog Drain[2]	Ridge	4.3	4.3	1.0	1.0	8.9	11.2	0
	Mid	---	4.0	---	0.5	---	7.2	0
	Bog	3.9	3.9	0.2	0.5	1.8	7.5	0
Ridge/Fen IV[3]	Fen	6.2	6.1	7.2	7.9	37.9	40.4	WM
Bog Drain III	Bog	4.1	4.1	0.5	0.5	7.8	12.6	0
Ridge/Fen	Fen	6.6	7.0	12.8	23.4	50.8	105.1	M
Mosaic A[3]	Bog	4.2	4.2	1.6	1.1	7.4	10.3	0
Ridge/Fen	Fen	4.8	4.6	1.6	1.6	13.8	11.1	0-WM
Mosaic B[3]	Bog	4.2	4.2	1.6	1.0	7.4	6.7	0
Ridge/Fen III		5.8	5.8	4.2	7.0	27.0	30.9	WM
Ridge/Fen I		6.1	6.4	6.8	7.1	31.6	35.7	WM
Upland Site A[4]		8.3	8.5	41.4	37.0	248.2	230.8	M
Upland Site C[4]		8.0	6.8	41.0	40.9	220.0	211.3	M

[1]M = minerotrophic site
WM = weakly minerotrophic site
0 = ombrotrophic

[2]The three measurements shown (ridge, mid,and bog) represent a transect across the bog drain from the ridge to the edge of the bog.

[3]Measurements at these sites were taken at ridge-associated fens and immediately adjacent bog drains.

[4]These sites were upland gravel pit pools and ditches found in the general area.

Table 8. Mean pH values of selected sites in the Porter Ridge Bog Area: April-October 1979. Three measurements were taken at each site each month. See Sect. 2.3. and 3.2. for details. See Appendix for location and description of sites.

Site / Month		April[1]	May	June	July	August	Sept	Oct
Wide Bog Drain[2]	Ridge	5.3	4.3	4.3	4.3	4.3	4.4	4.4
	Mid	4.4	4.2	4.1	4.0	4.1	4.1	3.9
	Bog	4.1	4.1	3.9	3.9	3.9	3.9	3.9
Bog Drain		4.1	4.2	4.1	4.1	4.0	4.1	4.1
Ridge/Fen Mosaic A[3]	Fen	---	6.7	6.7	7.0	6.6	6.6	Dry
	Bog	---	4.3	4.2	4.2	4.2	4.2	4.2
Ridge/Fen Mosaic B[3]	Fen	---	4.8	4.8	4.6	4.7	4.6	Dry
	Bog	---	4.3	4.3	4.2	4.2	4.3	4.2
Bog Drain III		4.3	4.1	4.1	4.1	4.0	4.0	4.0
Ridge/Fen IV		6.4	6.3	6.2	6.1	6.4	6.1	5.7
Ridge/Fen III		5.9	5.2	5.8	5.5	5.5	5.6	5.4
Ridge/Fen I		---	6.3	6.1	6.4	6.1	Dry	Dry
Upland Site A[4]		---	8.7	8.3	8.5	7.5	Dry	Dry
Upland Site B[4]		---	8.2	8.1	8.2	8.6	7.3	8.2
Upland Site C[4]		---	8.1	8.0	6.8	7.5	7.3	7.1

[1] Measurements are from late April after the influence of the spring thaw on water chemistry has diminished (see Sect. 3.2.).

[2,3,4] See legend, Table 7, for explanation.

(3) Minerotrophic waters: pH = 6.6-8.7; Ca content (ppm) = 12.8-41.0; "corrected" conductivity = 50.8-248.2. Examples: cedar swamp, "rich" upland (ridge)/fen areas, nonpeatland upland pools.

Our parameters for these categories are in general agreement with those given by Heinselman for sites in the nearby Lake Agassiz Natural Peatlands Area. These are general groupings and obviously not all sites can be so "pigeonholed". For example Ridge/Fen Mosaic B (Table 7) is intermediate between very poor ombrotrophic sites and weakly minerotrophic sites.

How constant are these parameters? As Heinselman (1970) points out there will be diurnal, seasonal, and weather-induced changes in water quality. Our results show generally stable conditions once the spring thaw has occurred. Table 8 shows pH values over the entire field season at selected sites. During the spring thaw there is a decided change in water chemistry as the influence of the snow pack gives way to vegetational and soil influences. For example at the Wide Bog Drain site the following change was noted in April, 1979: 4/12-pH=6.4 (melted snow); 4/14-pH=5.05 (ice/water/slush); 4/19-pH = 4.8 (open water); 4/21-pH = 4.5; 5/1-pH = 4.2. The other seasonal change noted was a relatively slight lowering of pH with very dry weather (example: Wide Bog Drain (mid), 9/10 - pH = 4.1; 10/10 - pH = 3.9; water levels dropped considerably over this period).

On a microscale (over distances of a few hundred meters within a given habitat or especially at transitions between habitat types) dramatic changes in water chemistry occurred. Again, similar results were found by Heinselman (1970). Such changes are the results of topographic, hydrologic,and vegetational influences interacting in complex fashion. The moatlike drain along the southern edge of Porter Ridge is a classic example. The drain carries water percolating off the bog complex to the south northward. The minerotrophic influence of the upland sandy soil ridge meets the ombrotrophic influence of the raised bog. There is a relatively slight gradient across the drain itself (Tables 7 and 8, Wide Bog Drain). At other sites the ridge chemistry dominates the near-ridge environment, which results in weakly minerotrophic to minerotrophic fens that abruptly give way to the ombrotrophic bog drains over distances of less than 100 meters. (See Tables 7 and 8 Ridge/Fen IV, Bog Drain III; Ridge/Fen Mosaic A; Ridge/Fen Mosaic B. See also Habitat Analysis Appendix for description of these sites.) For example at Ridge/Fen Mosaic A in July, pH dropped $\approx$ 3 units (7.0 to 4.2), calcium content dropped 20-fold (23.4 to 1.1 ppm), and conductivity 100-fold (105.1 to 10.3 μmhos) from the near ridge fen to the adjacent bog drain. Such changes obviously have ecological implications for all organisms that interact with the aquatic environment along the ridge.

3.3. Bog Water Toxicity Experiments

3.3.1. Fertilization. Bog water was not found to have an adverse effect on fertilization in the Wood Frog or American Toad. Comparison in the lab of samples of eggs from these two species showed no significant difference between the number of eggs fertilized in bog water versus control. (Example: American Toad--% eggs fertilized in bog water (n=100) = 96.0%; % eggs fertilized in control water (n=100) = 99%.) Freshly laid Wood Frog and American Toad egg masses from bog water sites showed normal fertilization. Examination of Wood Frog sperm in a bog water suspension showed motility and general activity identical to sperm in control water suspensions.

3.3.2. Egg hatching success. Bog water vs. control water (Table 9). Six of the eight amphibian species present in the general area were tested. Of these, five exhibited total inability to hatch in bog water. Only the Wood Frog had limited tolerance ($\bar{X}$ hatching success = 11.1%). Obviously bog water is an extremely deleterious breeding medium. Note also the percentage of coil seen (coil = eggs that exhibit advanced development, yet do not hatch). The Wood Frog eggs showed the highest percentage of coiling. All species' eggs in bog water showed some degree of coiling. The controls show virtually no

Table 9. Bog water toxicity I: egg hatching success-bog water vs. control water experiment. See Sect. 2.6.1. and 3.3.2. for details.

Treatment	Bog (pH=4.1-4.3)			Control (pH=7.1-7.6)		
Species Tested	%Hatch	No %Hatch	%Coil[1]	%Hatch	No %Hatch	%Coil
Rana sylvatica (Wood Frog) n=31 crosses[2] = 2168 eggs	11.1 (112)[3]	91.1 (921)	88.5 (815)	97.1 (1123)	2.9 (34)	2.9 (1)
Bufo americanus (American Toad) n=38 crosses =4060 eggs	0.0 (0)	100.0 (2018)	14.0 (282)	92.4 (1886)	7.6 (156)	0.0 (0)
Pseudacris triseriata (Chorus Frog) n=6 crosses =431 eggs	0.0 (0)	100.0 (229)	49.3 (113)	47.5 (96)	52.5 (106)	0.0 (0)
Hyla c. crucifer (N. Spring Peeper) n=5 crosses =532 eggs	0.0 (0)	100.0 (241)	---	60.1 (175)	39.9 (116)	1.0 (1)
Rana pipiens (N. Leopard Frog) n=12 crosses =1544 eggs	0.0 (0)	100.0 (435)	8.5 (37)	98.0 (1092)	2.0 (17)	0.0 (0)
Ambystoma laterale (Blue-spotted Salamander) n=2 crosses =158 eggs	0.0 (0)	100.0 (82)	26.8 (22)	97.4 (74)	2.6 (2)	0.0 (0)

[1]The term coil is used to indicate an unhatched egg in which the embryo has clearly reached an advanced stage of development yet is unable to hatch and eventually dies within the egg. Note that it is expressed as a percentage of the total number of unhatched eggs.

[2]Each cross represents a separate egg mass from which eggs were taken for the experiment. The total number of eggs taken from all masses for a given species is given below the number of crosses.

[3]The number in parentheses is the actual number of eggs counted for a given category. Statistical analysis: A 2x2 test of independence using the G-statistic was performed on each species. There were highly significant ($p<0.005$) differences between treatments for all species. The null hypothesis that hatching success is independent of treatment is rejected (Sokal and Rohlf, 1969).

coiling. Hence, the coil condition seems to be a phenomenon directly attributable to the bog water treatment. See Table 9 for statistical analysis.

Bog water dilution series (Table 10). A difference was exhibited between the ability of the two species tested (Wood Frog and American Toad) to tolerate bog water. For the Wood Frog the deleterious effect of bog water on hatching success was eliminated by 10% dilution (90% bog water; pH = 4.5) and greater dilutions.

The American Toad still exhibited very low hatching success (14.8%) at the 10% dilution (90% bog water; pH = 4.5) treatment. The 20% dilution (80% bog water; pH = 5.1-5.4) and greater dilutions showed normal hatching success.

There are also interesting differences in the coil condition. At 100% bog water Wood Frog eggs have a very high degree of coiling (82.7%). At 90% bog water Wood Frog hatching is normal but the coil condition (50%) persists. At dilutions > 90% no coiling is seen. Coiling of American Toad eggs is low at 100% (10.9%), high at 90% (64.0%), and persists through the 70% treatment. See Table 10 for statistical treatment.

Acidity gradient series (Table 11). Like the bog dilution series this test revealed differences in tolerance abilities between the two species tested (Wood Frog and American Toad). Wood Frog eggs were more acid tolerant and capable of normal hatching at pH $\geq$ 4.0. American Toad eggs were less tolerant and exhibited normal hatching at pH $\geq$ 4.5. At pH $\approx$ 4.0 Wood Frog eggs showed a 93.7% hatching success whereas American Toad eggs exhibited only 2.3% hatching success.

The coil condition was seen in the Wood Frog eggs at pH = 4.0 and 4.5 but not in large numbers as in the bog dilution series. The toad eggs had a 27.0% level of coil at pH = 4.0 with a few coiled eggs at 4.5 and 5.0. See Table 11 for statistical analysis.

Table 10. Bog water toxicity II: egg hatching success-bog water dilution experiment. See Sect. 2.6.1. and 3.3.2. for details.

Species	*Rana sylvatica* (Wood Frog) n=4 crosses[2] =1095 eggs			*Bufo a. americanus* (American Toad) n=4 crosses =1669 eggs			
Treatment:							
% Bog Water	%Hatch	No %Hatch	%Coil[1]	% Bog Water	%Hatch	No %Hatch	%Coil
100.0 (pH=4.2-4.3) n=124	12.1 (15)[3]	87.9 (109)	82.7 (90)	100.0 (pH=4.2) n=192	0.0 (0)	100.0 (192)	10.9 (21)
90.0 (pH=4.4-4.7) n=134	92.5 (124)	7.5 (10)	50.0 (5)	90.0 (pH=4.5) n=189	14.8 (28)	85.2 (161)	64.0 (103)
80.0 (pH=5.3-5.5) n=132	95.5 (126)	4.5 (6)	0.0 (0)	80.0 (pH=5.1-5.4) n=217	98.2 (213)	1.8 (4)	75.0 (3)
70.0 (pH=6.2) n=128	98.4 (126)	1.6 (2)	0.0 (0)	70.0 (pH=5.9-6.5) n=229	98.3 (225)	1.7 (4)	25.0 (1)
60.0 (pH=6.6) n=117	100.0 (117)	0.0 (0)	0.0 (0)	60.0 (pH=6.5-7.0) n=218	96.8 (211)	3.2 (7)	0.0 (0)
40.0 (pH=6.8-7.0) n=139	99.3 (138)	0.7 (1)	0.0 (0)	40.0 (pH=6.9-7.0) n=224	95.1 (213)	4.9 (11)	0.0 (0)
20.0 (pH=7.1-7.2) n=150	98.0 (147)	2.0 (3)	0.0 (0)	20.0 (pH=7.1) n=201	95.5 (192)	4.5 (9)	(0) (0)
Control (pH=7.1-7.6) n=171	97.7 (167)	2.3 (4)	C.0 (0)	Control (pH=7.1-7.6) n=199	96.0 (191)	4.0 (8)	0.0 (0)

[1,2,3] See legend, Table 9, for explanation. Statistical analysis: A two-way analysis of variance without replication was performed. An arcsine transformation was applied to the data to allow use of this test. This test showed a significant ($0.01>P>0.001$) effect on hatching success due to treatment. There was no significant ($p>0.05$) effect due to the different crosses used. A Student-Newman-Keuls test was used to compare means among treatments. The effect of the 100% treatment was significantly different from all other treatments for both species. The toad 90% treatment was significantly different from the 100% treatment and from the remainder of the treatments ($0.05 > p > 0.01$) (Sokal and Rohlf, 1969).

Table 11. Bog water toxicity III: egg hatching success--acidity gradient experiment. See Sect. 2.6.1. and 3.3.2. for details.

Species Tested Treatment:	*Rana sylvatica* (Wood Frog) n=4 crosses[2] =1035 eggs				*Bufo americanus* (American Toad) n=4 crosses =1641 eggs		
pH (pH range)[4]	%Hatch	No %Hatch	%Coil[1]	pH (pH range)	%Hatch	No %Hatch	%Coil[1]
3.0 (3.0) n=168	0.0 (0)[3]	100.0 (168)	0.0 (0)	3.0 (3.0) n=209	0.0 (0)	100.0 (209)	0.0 (0)
3.5 (3.5-3.6) n=154	0.0 (0)	100.0 (154)	0.0 (0)	3.5 (3.4-3.6) n=208	0.0 (0)	100.0 (208)	0.0 (0)
4.0 (3.9-4.0) n=142	93.7 (133)	6.3 (9)	55.6 (5)	4.0 (4.0-4.1) n=262	2.3 (6)	97.7 (256)	27.0 (69)
4.5 (4.5-4.7) n-126	96.8 (122)	3.2 (4)	50.0 (2)	4.5 (4.5-4.6) n=276	97.8 (270)	2.2 (6)	66.7 (4)
5.0 (5.0-5.7) n=129	99.2 (128)	0.8 (1)	0.0 (0)	5.0 (5.0-5.2) n=220	83.6 (184)	16.4 (36)	5.6 (2)
6.0 (6.0-6.5) n=129	96.9 (125)	3.1 (4)	0.0 (0)	6.0 (6.0-6.4) n=215	98.1 (211)	1.9 (4)	0.0 (0)
Control (7.2-7.6) n=187	97.9 (183)	2.1 (4)	0.0 (0)	Control (7.2-7.5) n=251	94.8 (238)	5.2 (13)	0.0 (0)

[1,2,3] See legend, Table 9, for explanation.

[4] Drift in pH in the test chambers around the desired value was unavoidable. The number in parentheses beneath the target pH value gives the range of values recorded during the course of the experiment. Statistical analysis: A two-way analysis of variance without replication was performed. An arcsine transformation was applied to the data to allow use of this test. The test showed a highly significant ($p<0.001$) effect due to treatment. There was no significant effect ($p>0.05$) due to the different crosses used. These results apply to both species. For the WoodFrog a Student-Newman-Keuls (SNK) test was used to compare means among treatments. pH 3.0 and 3.5 treatments were significantly ($p<0.05$) different from the remainder of the treatments. The SNK test was also applied to the toad. There was a significant ($0.05>p>0.01$) difference between the 3.0, 3.5, and 4.0 treatments and the remainder of the treatments (Sokal and Rohlf, 1969).

Bog water and buffer. These tests showed that for the Wood Frog, American Toad, and N. Spring Peeper the deleterious effects of bog water on hatching success could be eliminated by artificially raising the pH with the addition of buffering agents ($CaCO_3$ for the Wood Frog, NaOH for the toad and N. Spring Peeper). The Wood Frog treatment was raised to $\approx$ 5.0. The toad and N. Spring Peeper treatments were raised to around neutrality ($\approx$7.0).

The number of Wood Frog eggs hatched was 2/76 (2.6%) in the bog water and 89/92 (96.7%) in the buffered treatment. The number of toad eggs hatched was 0/185 (0.0%) in the bog water and 173/178 (97.2%) in the buffer treatment. The N. Spring Peeper produced 0/77 (0.0%) hatched eggs in the bog water and 44/52 (84.6%) in the buffer treatment. These differences are highly statistically significant ($p < 0.005$, 2x2 test of independence using the G-statistic, Sokal and Rohlf, 1969).

Temperature. For both species tested (Wood Frog and American Toad) cold bog water ($\approx$3.5^{o}C) had a greater deleterious effect than warm bog water ($\approx$15.5^{o}C). This effect did not manifest itself in hatching success. For both species hatching success was near zero in bog treatments. There were differences in the coil condition however. The Wood Frog showed a 77.7% (n=179 unhatched eggs) coil level in the warm treatment and 0.0% (n=140 unhatched eggs) in the cold. The American Toad coil level was 10.9% (n=192 unhatched eggs) and 0.0% (n=219 unhatched eggs) in the warm and cold treatments respectively. This indicates that warm bog water allows development to proceed at some level whereas the cold effectively kills the eggs at early developmental stages. The differences in degree of coil condition seen were statistically significant ($p < 0.005$, 2x2 test of independence using the G-Statistic, Sokal and Rohlf 1969).

Microhabitat variation. This test showed that the variation in water quality across a 100-meter wide bog drain is great enough to cause significant differences in the hatching success of Wood Frog eggs. In water from the ridge side where minerotrophic influences are greatest, hatching success was 42.3% (47/111 eggs). With water from the ombrotrophic-influenced bog side of the drain hatching success dropped to 2.6% (2/76 eggs). Clearly the exact location of egg deposition could be extremely important. Coiling is high at both sites. The differences in hatching success are highly statistically significant ($p < 0.005$, 2x2 test of independence using the G-statistic).

Field observation. The experiments described above show that bog water has a significant effect on eggs in the lab. Do such effects occur in nature? Wood Frog eggs that were brought in from the field at advanced stages and allowed to hatch in the lab showed a wide range of variability in hatching success and percentage of the coil condition. This variation is to be expected as indicated by the results of the microhabitat variation experiment. For example, at six ombrotrophic bog drain sites sampled hatching success varied from 0.0% to 42.3%. The percentage of the coil condition seen varied from 0.0% to 86.1%. At three weakly minerotrophic fen sites sampled, hatching success varied from 91.5% to 94.9%, and the coil condition was not seen.

General casual observation of Wood Frog egg masses at ombrotrophic sites indicated a high level of mortality.

3.3.3. Larval survivorship. Bog water dilution series (Table 12). 100% bog water is highly toxic to five of the six species tested. As in the egg hatching tests only the Wood Frog shows tolerance to any degree. Note the difference in survivorship for Wood Frog larvae hatched in bog water versus those hatched in control. The deleterious effect of the bog water is eliminated for all species except the Chorus Frog by 10% dilution (90% bog water). For the Chorus Frog a 20% dilution (80% bog water) eliminates the effect. For the American Toad there was a significant deleterious effect at 90% bog water on hatching success, but this does not seem to be the case with the larvae. Hence, the deleterious effect of the bog water on larvae is similar to that on egg hatching success; the effect is removed by relatively slight dilution.

Table 12. Bog water toxicity IV: larval survivorship-bog water dilution experiment. See Sect. 2.6.1. and 3.3.2. for details.

Species Tested: % Survivorship after 96 hours	% Bog Water						
	100.0 (pH=4.2-4.3)	90.0 (pH=4.4-4.5)	80.0 (pH=5.1-5.2)	60.0 (pH=6.5)	40.0 (pH=7.0)	20.0 (pH-7.2)	Control (pH=7.5)
Rana sylvatica (Wood Frog)	31.7[1] 83.3 (60)[2]	100.0 (30)	100.0 (30)	96.7 (30)	100.0 (30)	96.7 (30)	96.7 (60)
Bufo americanus (American Toad)	0.0 (60)	90.0 (60)	100.0 (30)	96.7 (30)	93.3 (30)	100.0 (30)	100.0 (40)
Pseuadcris triseriata (Chorus Frog)	0.0 (40)	15.0 (40)	100.0 (20)	100.0 (20)	95.0 (20)	100.0 (20)	100.0 (40)
Hyla c. crucifer (N. Spring Peeper)	6.7 (30)	100.0 (30)	100.0 (30)	100.0 (30)	96.7 (30)	100.0 (30)	100.0 (30)
Rana pipiens (N. Leopard Frog)	0.0 (60)	96.7 (30)	100.0 (30)	100.0 (30)	96.7 (30)	96.7 (30)	97.5 (40)
Ambystoma laterale (Blue-spotted Salamander)	0.0 (20)	100.0 (20)	100.0 (20)	100.0 (20)	100.0 (20)	100.0 (20)	100.0 (20)

[1]For the Wood Frog alone larvae were available that had been hatched in control water and bog water. In the 100% bog water test the upper number is survivorship of control hatched larvae and the lower number is survivorship of bog hatched larvae.

[2]The number in parentheses below each survivorship figure is the total sample size (n) for each treatment. Statistical analysis: a two-way analysis of variance without replication was performed. An arcsine transformation was applied to the data to allow use of the test. The test showed a highly significant ($p<0.001$) effect due to treatment. There was also a significant ($0.05>p>0.01$) effect due to differences among species. A Student-Newman-Keuls (SNK) test was used to compare means among treatments. For all species there was a significant ($0.05>p>0.01$) differences between the 100% bog water treatment and the remainder of the treatments. Additionally, for the Chorus Frog there was a significant difference between the 90% treatment and the remainder of the treatments (Sokal and Rohlf, 1969).

See Table 12 for statistical analysis.

Larval surveys. These surveys indicated that amphibian larvae were either rare or absent at bog water sites. Only one Wood Frog larva was ever found at a site of ombrotrophic quality. As noted previously, Wood Frog eggs do hatch at bog water sites, and larvae could be found when this hatching was in progress. The surveys were done in June and July well after the hatching period was over. Weakly minerotrophic to minerotrophic sites produced many larvae of all species.

Larval rearing experiments. An attempt was made to rear Wood Frog larvae through metamorphosis in a bog water environment on a bog drain vegetation diet. Of the 60 larvae reared only one survived through to metamorphosis. Survival of larvae to near metamorphosis in control water was 95% (n=100). Hence it is possible for Wood Frog larvae raised in bog water to develop into adults (at least in the lab), but bog water is clearly not an optimal environment.

3.3.4. Adult survivorship. Does prolonged immersion of fully developed amphibians in bog water result in decreased survivorship compared to prolonged immersion in control water? (Note that well water was used as the control; the well water was hard, alkaline water, which proved to be a fine medium for hatching eggs, rearing larvae, and maintaining adults for all species). The two dominant peatland amphibian species, the Wood Frog and American Toad, were tested. No statistically significant difference ($p>0.05$) was found between survival time in bog water and in control water for either species. Fifteen indviduals of each species were tested in both bog and control water. This result indicates that bog water does not have a deleterious effect on the adult form of the species tested. A 2x2 test of independence using the G-statistic was the statistical test employed (Sokal and Rohlf 1969).

3.4. Overwintering Experiments

3.4.1. Hydration stress test. The Wood Frog and American Toad exhibited significant differences in their abilities to tolerate prolonged immersion in distilled water. Mean survival time of the Wood Frog was 27.2 days (n=30, range=6-100 days). The American Toad's average survival time was 14.2 days (n=30, range=8-26 days). This is a statistically significant difference ($p<0.005$, chi-square analysis, Sokal and Rohlf 1969).

3.4.2. Coldroom overwintering experiment. This experiment is still in progress. The initial results are as follows:

American Toad. Two week check--wet peat soil = 15/16 (93.8%) toads dead; sand soil = 1/13 (7.7%) toads dead. Six week check--wet peat soil = 16/16 (100%) toads dead; sand soil = 1/13 (7.7%) toads dead.

Wood Frog. Two week check--wet peat soil = 8/16 (50.0%) frogs dead; sand soil = 0/14 (0.0%) frogs dead. Six week check--wet peat soil = 14/16 (87.5%) frogs dead; sand soil = 9/14 (64.3%) frogs dead.

The Wood Frog results must be considered with caution. Signs of Red Leg (a common bacterial infection of frogs) were observed on some of the dead frogs and may have contributed to mortality. The toads apparently have not been infected. For the toad,at least,there is a clearcut increase in mortality associated with the wet peat soil treatment.

4.0 DISCUSSION AND SUMMARY

4.1. Nature of the Peatlands Herpetofauna

Three main generalizations concerning the nature of the boreal peatlands herpetofauna emerge from the information collected in the course of this research program.

4.1.1. Dominance of amphibians. Amphibians are the dominant element of the peatlands herpetofauna. In the general study area eight species of amphibians representing two orders and five families were found. Four species of reptiles representing two orders and three families are found. Amphibians are extremely abundant and undoubtedly represent an important percentage of the vertebrate biomass in the peatlands.

4.1.2. Species composition. No peatland specialists were found; by this we mean no species were found that were restricted to peatland habitats. The herpetofauna is composed largely of generalist species, noted for the wide range of habitats in which they are found.

This finding contrasts with findings in other bog areas that have been studied. For example, the bogs of the New Jersey Pine Barrens are noted for the presence of *Hyla andersoni* (Pine Barrens Tree frog). This is an endangered species, which breeds preferentially in sphagnum pools of the area. Also from the east coast is the more widely spread *Rana virgatipes* (Carpenter Frog, also called the "sphagnum frog") noted for its close association with peat bog habitats (Conant 1975; Gosner and Black 1957; Smith 1978; and Noble 1928).

We found no localized species of this nature for which the peatlands could be designated as critical habitat. The Wood Frog and American Toad were the dominant peatlands habitat species. The Wood Frog was the only species found to show tolerance to the toxic effects of bog water in reproductive success. It is also relatively tolerant to hydration stress. This species appears to be the best suited to cope with the unusual characteristics of peatland habitats. However, it is by no means restricted to such areas.

4.1.3. Low relative species diversity; the restricitve nature of peatland habitats. The peatlands do not have a diverse herpetofauna. Amphibians and reptiles are, however, abundant in the areas studied; there are many individuals of relatively few species. In part this is expected; amphibians and reptiles are ectotherms suited to warmer, particularly tropical, environments where they are abundant and rich in species. They are not "good" northern colonizers. For example, if one looks at the number of species of frogs and toads in areas progressively farther north the following is found: Mexico (161); Washington State (11); Minnesota (14); Alaska (3). There is a striking latitudinal dropoff in the number of species. The peatlands studied, however, seem to be poor even for a northern temperate herpetofauna (see Progress Report No. 5, Sect. 4.1.2.). There seems to be something about the peatlands studied that restricts amphibian and reptile colonization.

A major goal of this research program was to determine what factors might be involved in making peatlands unsuitable for herpetofaunal utilization. The Porter Ridge Bog intensive study site provides a natural experiment in which bog and upland habitats lie side by side.

4.2. Factors Controlling Peatland Habitat Utilization

As noted above, there seems to be something restrictive about peatland habitats in general compared to nonpeatland areas. Even within the group of species found in the study area, most avoided the common and widespread sphagnum-dominated semiraised to raised bog sites. Within the two amphibian species (Wood Frog and American Toad) common in these areas there were important seasonal differences in the number and age-size class of individuals caught compared to immediately adjacent nonpeatland areas. What are the key factors involved in the creation and maintenance of the patterns of distribution and utilization?

4.2.1. Distribution of water resources in peatlands. The peatlands in many areas can be thought of as a vast, shallow, poorly drained subsurface river. Because of this I suggest that for many amphibian and reptile species the area may be either too wet or that the water present is distributed inequitably. The water-saturated soils of the area may prohibit species requiring drier conditions. This may be a factor in the relatively low number of terrestrial reptiles found. For some species the problem is different. The general scarcity of permanent, larger, deeper bodies of water (e.g. ponds, lakes) may also prohibit colonization by certain aquatic amphibians and turtles (see Progress Report No. 5, Sect. 4.1.2. for examples).

4.2.2. Microclimate. Temperature and precipitation are major factors controlling habitat utilization by amphibians and reptiles (Porter 1972). Temperature can be thought of as a habitat "gatekeeper" for these ectothermic animals; a habitat cannot be utilized until average microhabitat temperatures fall within a given species' thermal activity range. This has important ecological consequences for the herpetofaunal community, particularly in the spring. In both 1978 and 1979 the sphagnum black spruce bog sites remained colder, longer compared to adjacent upland sites. In both years there was a month's delay between the first movements at the upland sites and those at the bog sites. For early breeding amphibians there is a definite penalty for overwintering in the bog. Strong Wood Frog chorusing and egg laying was occurring in late April at Porter Ridge in the open fens and bog drain. In the immediately adjacent bog there was still 50% snowcover and largely frozen substrate.

The summer-through-fall ground level and substrate temperatures indicated that mean minimum temperatures dropped somewhat with distances from the ridge, but mean maximum temperatures were similar (Table 1A, 2A, Appendix). This means the bog habitats presented a more thermally variable environment with greater extremes throughout the summer and fall.

In October the mean minimum temperature at Raised Bog I was 8.3^{o}C lower than that at the adjacent Ridge I site. Such differences would undoubtedly influence overwintering activity.

The old adage that the bogs are the "first to freeze and the last to thaw" is certainly borne out by our data and has extremely important consequences for amphibians and reptiles in these areas.

Rainfall is not the key factor in peatland habitats that it is in drier areas. Except in times of extreme drought, scarcity of water would not be a problem in the peatlands studied. Rainfall, however, is important in initiating local movements. It was found in this study and many others (e.g. Savage 1961; Voght and Hine 1977) that amphibians, in particular, move in greater abundance during wet and/or extremely humid periods. Precipitation in the form of snow is also important in early spring in determining the initiation of seasonal activity.

4.2.3. Food resources. The possibility that there are differences in the availability and type of food resources found among various peatland habitats and nonpeatland areas exists. The very limited survey done in the course of this study between a raised bog site and an adjacent upland site provides support for such a hypothesis. A fourfold difference in insect abundance was found between the two sites. We predict that important differences, if they do occur, are to be found between the extremely nutrient-poor ombrotrophic habitats and the richer minerotrophic sites. Such differences clearly have ecological consequences for the herpetofauna and may help explain the lower abundance and age and size differences noted at Porter Ridge Bog.

4.2.4. Water balance. Amphibians are not "well-designed" terrestrial animals. They are constantly losing water through evaporation even when humidity is high (Porter 1972). Water-saturated peatland habitats are clearly a resource for such organisms. For metamorphosed individuals, all that is important is body contact with a wet substrate, hence the limitations on water availability noted above do not apply.

Peatland habitats, except perhaps in times of extreme drought, can perhaps be considered as osmoregulatory refuges in which favorable water balance conditions can always be found. These conditions may be an important factor in the disappearance of animals from the drier uplands (Progress Report No. 5, Sect. 3.2.3.).

4.2.5. Water-saturated soils and overwintering. Both amphibians and reptiles in the area studied spend approximately half of the year dormant, burrowed in at overwintering sites. Without the proper sites and/or under severe winter conditions mortality can be high. Overwintering sites are clearly key resources.

The available evidence suggests that water-saturated habitats may offer severe constraints on where amphibian overwintering can successfully occur. Unfortunately it is not known exactly where peatlands amphibians do overwinter. Such information would require tagging individuals with radioactive wires or micro radio transmitters and following them.

Amphibians differ in their ability to tolerate sustained immersion in water (Schmidt 1965; Karns, this study sect. 3.4.). The coldroom experiments performed indicate that the American Toad and to a lesser extent the Wood Frog cannot tolerate water-saturated peat as an overwintering medium. Recent studies (Hodge 1976; Ewert 1969) indicate that overwintering survival is apparently correlated with the dryness of the site for some species. These studies indicated that under natural conditions mortality was high at wet sites for the Wood Frog and American Toad. This work supports our lab findings.

The above information suggests that the two dominant species in the peatlands studied are not physiologically capable of overwintering at wet bog sites. However, indirect evidence from emergence data indicate that at least some do. The answer to this discrepancy may lie in the hummock and hollow microtopography of sphagnum bogs. These mounds rise up to two feet above the water table. The central sphagnum in these mounds is moist but certainly not water saturated. During the winter the surface of these mounds freezes; amphibians cannot tolerate freezing temperatures. However, there may exist safe zones in these mounds between the frozen surface layer and the underlying water table in which amphibians can safely pass the winter. If such mounds freeze to the water table, mortality would probably result. Observations to be made next spring will clarify this possibility.

4.2.6. Bog Water Toxicity. The documentation of bog water toxicity as it relates to amphibian reproduction has been a major goal of this research program. The results of the lab and field research in this area are discussed in detail in the following section. Bog water was shown to have toxic properties and cause high mortality of amphibian embryos and larvae. Such an ecologically potent environmental factor could obviously be important in shaping the patterns of distribution and habitat utilization noted. It is important to stress that it is ombrotrophic bog water (defined in Sect. 2.6.1.) that causes toxic effects, and that there is variability among sites. The water in peatlands is not uniformly toxic to amphibian embryos and larvae. In some areas, however, bog water toxicity is an extremely important local ecological factor.

Many authors have noted a reduction in vertebrate species diversity associated with acidic bog and blackwater habitats compared to clear water, moderate pH environments (see Saber and Dunson, 1978 for a review). Janzen (1974) has championed the idea that these differences are directly attributable to toxic effects of the high content of humic substances (leached from plant material) found in the waters of these areas. Other authors suggest that acidity *per se* is a dominant factor in reduction of species diversity. We agree entirely with the thesis that bog water toxicity, whatever the mechanism involved, is an important factor in peatland environments.

However, as can be seen from the preceding discussion there are other powerful factors to be considered as well. It is all these factors combining in various ways from site to site that produce the unusual nature of the peatlands and in consequence create the patterns of herpetofaunal distribution and habitat utilization observed.

4.3. Peatland Water Chemistry, Bog Water Toxicity, and Amphibian Reproduction

4.3.1. Water quality. Water quality is clearly an important parameter to consider as the bog water toxicity experiments indicate. It must be stressed again that there is a spectrum of water quality available in the peatland areas studied ranging from ombrotrophic (e.g. bog drain) to strongly minerotrophic (e.g. cedar swamp), (see Sect. 3.2.). Only water at the ombrotrophic end of the scale exhibited toxic effects on amphibian eggs and larvae. Toxic effects occur only in areas where topography, hydrology, and vegetation interact in such a way to allow the bog vegetation (especially sphagnum) to dominate the chemical environment.

This interaction occurs at sites such as raised bogs, bog drains, and the edges of black spruce islands and also on a smaller scale in sphagnum hollow situations. There is dramatic variation in water quality across short distances, which is ecologically important. Peatland habitats are certainly not uniformly deleterious to amphibian reproduction. There is a great deal of heterogeneity.

4.3.2. Bog water toxicity. The documentation of bog water toxicity was an important goal of this investigation. Again it must be stressed that we use the term bog water to indicate water from ombrotrophic sites that is highly acidic, showing low electrolyte content, and highly colored (see Sect. 2.6.1.). For the lab tests all bog water used came from one site. Effects of bog water on fertilization, eggs, larvae, and adults were investigated. In the following section each major area studied will be summarized, discussed, and compared with pertinent information from other studies.

Fertilization. For the two species studied (Wood Frog, American Toad) bog water was found to have no adverse effect on fertilization. Amphibians fertilize their eggs externally. The female extrudes the eggs into the water while the clasping male simultaneously sheds his sperm. Hence, fertilization occurs in the breeding medium.

Gosner and Black (1957) reported egg cleavage (indicating fertilization) frequencies of 47% and 100% for two pairs of the N. Spring Peeper held in New Jersey Pine Barrens bog water (pH = 4.2-4.5). They also reported $\approx$ 100% fertilization for Pseudacris nigrita kalmia (=Pseudacris triseriata kalmia under current nomenclature = New Jersey Chorus Frog) in bog water at pH = 4.7.

These findings suggest that fertilization is not the crucial phase in producing the toxic effect of bog water.

Egg hatching success. In laboratory tests bog water (pH = 4.2) proved to be a lethal hatching medium for five of the six species tested (American Toad, Chorus Frog, N. Spring Peeper, N. Leopard Frog, and Blue-spotted Salamander). Only the Wood Frog exhibited any hatching success ($\overline{X}$ = 11.1% vs. 0.0% for the other species). The coil condition was seen in all species' unhatched eggs exposed to bog water (i.e. the embryo reached an advanced stage of development but was apparently unable to hatch).

Only two other studies have been located that deal experimentally with amphibian reproduction and bog water toxicity. Gosner and Black (1957) worked in the New Jersey Pine Barrens, and Saber and Dunson (1978) in a Pennsylvania bog. Both papers report that acidic bog water (pH = 4.0-4.3) affected the hatching success of some species. Gosner and Black's lab experiments indicated that the amphibian community in the New Jersey Pine Barrens bog studied was in general more tolerant to bog water than the Minnesotan amphibian community studied. Six out of the twelve species tested exhibited hatching success $\geq$ 50% in bog water of pH $\approx$ 4.1. (Two of these species, the Wood Frog and N. Leopard Frog, are found in our study area.) Bog water of this pH was extremely deleterious to all Minnesota species tested. Saber and Dunson reported Bullfrog embryo mortality in acidic bog water but also at higher pH's (pH 5.7-6.6). We did not find mortality associated with such moderate pH water. It must be stressed that there are problems in comparing studies using bog water from different geographic areas.

Acidity experiments. H_2SO_4/H_2O treatments did not mimic the effects of bog water of equivalent pH on hatching success and percentage of coiling. This result indicates that more than just acidity is involved in bog water toxicity. Wood Frogs and toads differed in their ability to tolerate H_2SO_4 acidity, the Wood Frog being more acid tolerant.

Gosner and Black (1957) also tested egg hatching success at different levels of acidity. They used hydrochloric acid (HCl) rather than H_2SO_4 as the acid, and this difference makes comparison difficult. They found that egg response to bog water and acidified water of similar pH was equivalent. We did not get this result with the H_2SO_4/H_2O treatments. Using the HCl system they found very acid-tolerant species; Hyla andersoni (Pine Barrens Frog), Rana virgatipes (Carpenter Frog), and the Wood Frog showed $\geq$ 50% fertilization at pH values < 4.0. For eggs of these species they estimated the lethal pH at $\lesssim$ 3.4, $\approx$ 3.4, and 3.5 respectively. H_2SO_4 more closely approximates the natural acidity found in bogs (Gorham, personal communication), and we consider it to produce a more realistic test of acid tolerance. Like their bog water tests, the Gosner and Black acidity experiments indicate a generally more acid-tolerant amphibian community than we found in Minnesotan peatlands, but comparison is difficult because of different techniques.

The experimental techniques used by Pough and Wilson (1976) more closely approximate our system. They investigated the effects of acid rain on reproductive success of two species of salamanders. Their lab experiments used H_2SO_4/dechlorinated tap water breeding mediums of various pH. They found that the salamanders tested had different acid tolerances (<u>Ambystoma jeffersonianum</u> tolerated pH = 4-8 with greatest hatching success at pH = 5-6; <u>Ambystoma maculatum</u> tolerated pH = 6-10 with greatest success at pH = 7-9). Of more particular interest is a footnote in which Pough (1976) notes that Wood Frog embryos tolerate pH levels "at least as low as pH 4." Hence, using H_2SO_4 as the test acid produced results comparable to ours.

<u>Buffering Experiments</u>. The toxic effect of bog water (on hatching success and percentage of coiling) can be eliminated by artifically raising the pH with a buffering agent ($CaCO_3$ or NaOH). This result indicates that acidity can control the toxicity of bog water in some manner. Wood Frog and American Toad were the test species.

Saber and Dunson (1978) found that mortality of African Clawed Frog embryos was significantly greater in unaltered bog water (pH 4.0-4.3) than in bog water neutralized with NaOH (pH 7.09-8.16). Tests with the Green Frog and Bullfrog showed zero mortality with moderately acidic bog water of pH 4.32-4.62 and zero mortality with neutralized bog water. These results are consistent with our findings.

<u>Temperature</u>. The deleterious effect of cold bog water ($\approx 3.5^{o}C$) was more severe than that of warm ($\approx 15.5^{o}C$) bog water. It is not clear why such an effect occurs. In physio-chemical processes increases in temperature speed up biochemical reactions. Such an acceleration of events might be expected to accentuate the toxic effects of the bog water; this is apparently not the case. Cold temperatures on the other hand slow down the rate of biochemical events. The net effect of lower temperatures on amphibian eggs is to increase development time with resultant prolongation of exposure to the toxic bog water. For example development time with the Wood Frog at $15.5^{o}C$ is $\approx$ 275 hours, at $3.3^{o}C \approx$ 850 hours (Rugh 1941; personal observation). This $12.2^{o}C$ lowering of temperature results in a threefold increase in development time. Such a prolongation may be an important factor in producing the observed effects.

Obviously stable laboratory temperatures are not ecologically realistic. Field max/min temperatures taken at Wide Bog Drain from May 1 to May 5, 1979 showed ranges from 2.2-24.0°C. Wood Frog eggs were developing there during this period. Field notes record a period of $\approx$20 days (480 hours) from the first observation of eggs to the first observation of hatching. The 1979 spring season was relatively cold and wet with many cloudy days. The lab results suggest that such conditions could increase mortality in Wood Frog eggs, which are capable of bog water hatching. It is possible that even less bog water/acid-tolerant species like the American Toad might be able to hatch under particularly warm conditions. Also time of breeding is important. The range of temperatures from May 15 to May 31 at the Wide Bog Drain was 5.6-28.9°C; conceivably amphibians breeding later would encounter a warmer and thus relatively less deleterious bog water breeding medium.

Pough and Wilson (1976) noted differences in the hatching success of two species of salamanders at different pH/temperature conditions. These were lab experiments with H_2SO_4/dechlorinated tap water treatments. One species hatched successfully at relatively low pH and cool temperatures whereas the other required warmer temperatures and higher pH. These findings plus our results indicate the general ecological importance of the pH/temperature interaction for amphibian reproductive success.

Microhabitat variation. Both field and lab observations indicated the heterogeneity of breeding site quality on a microscale. Sites 20 to 40 meters apart produced dramatic differences in hatching success. Water quality appears to be a major factor in these differences. Obviously many factors are involved in producing the overall quality of a given site. Relatively subtle variation in water quality can produce major differences in hatching success. Ridge/Fen Mosaic B (Table 7) is a good example. Saber and Dunson (1978) also reported large differences in egg mortality between bog water treatments that differed only slightly in pH.

Larval tolerance. Obviously if the eggs of a given amphibian species cannot hatch in bog water then the ability of the larvae of that species to tolerate bog water is ecologically irrelevant. The relatively bog water-tolerant Wood Frog can hatch in bog water and for this species the question is ecologically relevant. Other species, however, do breed in bog water. Lab and field observations indicate that conditions are subtle enough so that hatching may occur at bog water sites. Can larvae tolerate bog water if hatching does occur? The possibility had to be considered that the toxic properties of bog water might involve only the egg and hatching ability. Bog water was perhaps a perfectly fine medium for rearing amphibian larvae.

This turned out not to be the case. Five of the six amphibian species tested showed zero or very low survivorship in 100% bog water. Again only the Wood Frog showed any substantial tolerance. The toxic effect of the bog water was eliminated by mild dilution for all species tested. Wood Frog larvae hatched in bog water exhibited a much higher tolerance than Wood Frog larvae transferred from control water (83.3% vs. 31.7% survivorship). Since the other species could not hatch in bog water,they were necessarily transferred from control water. Direct transfer from control to bog water is of course unnatural and potentially physiologically traumatic to the larvae. No attempt was made to acclimate the larvae through a series of dilutions (this would've been equally unnatural). The point remains that larvae can be switched back and forth between various other mediums (i.e., control, upland fen water, well water) with no problems,but transfer to bog water results in mortality.

Saber and Dunson (1978) also reported larval bog water mortality for the Green Frog, Bullfrog,and *Bufo* spp. They also reported that mortality varied with stage of development. Bullfrog larvae stages 22-26 suffered 100% mortality in field bog water toxicity tests whereas stages 32-38 suffered only 16.7%. All larvae used in our tests were recently hatched (stage 24-26).

Wood Frog larvae,then,are able to hatch and develop in bog water in the lab. Other species tested do not appear to tolerate bog water under lab conditions (which must be considered fairly optimal). As the previously described tests indicate, relatively subtle variations in water quality may allow hatching. Hence, in the complex and variable conditions found in nature eggs may be hatching and larvae surviving. Wood Frogs appear to be the most likely to be found,but it is possible that other species could also be found. Extensive field surveys indicate that larvae of any species are either rare or absent at ombrotrophic bog water sites. In the June/July surveys only one Wood Frog larva was found at a bog water site.

Weakly minerotrophic to minerotrophic sites always produced larvae in abundance. Areas searched were purposefully near known breeding sites in order to maximize catching success. This finding does not eliminate the possibility that larvae are present at bog water sites,but certainly indicates that they are not common compared to "normal" sites.

If larvae are present, could they develop and metamorphose into adult form in a bog water environment on a bog vegetation diet? Amphibian larvae are herbivores and graze on plant material in the water using rasping structures on the suckerlike mouth. Bog plants including sphagnum are known to be rich in plant phenolics including tannins.

Tannins in small amounts are known to produce growth inhibitory effects in mammalian herbivores (Van Sumere 1975). It is possible that feeding on phenolic-rich plant material could produce deleterious effects in addition to the effects of being immersed in the bog water itself.

Out of 60 Wood Frog larvae kept in a bog water/bog vegetation test regime only one survived through metamorphosis. Hence,the possibility remains that there are larvae surviving and maturing at bog water sites in the field.

<u>Adult tolerance</u>. Bog water is a deleterious medium for amphibian eggs and larvae. It is conceivable that the toxic properties of bog water could also affect adults. Amphibians constantly lose water from their skins even when humidity is high (Porter 1972). The amphibian skin acts as an osmoregulatory organ, and uptake of water from the organism's surroundings is important. Adult amphibians in bog habitats would certainly be exposed to the potential toxic effects of bog water during the breeding season, subsequent summer movements, and overwintering.

Adult Wood Frogs and American Toads of various sizes and sex showed approximately equal survival times when immersed in bog water or control water. This result indicates that bog water is not toxic to adults.

4.3.3. <u>General Comments</u>. <u>Bog water toxicity and egg hatching</u>. Egg hatching is clearly a crucial link in the inability of breeding amphibians to utilize ombrotrophic bog water areas as successfully as more minerotrophic areas. The above experiments provide some clues about the mechanism of bog water toxicity. Bog water is a complex biochemical solution and the probability that several factors are acting in a synergistic fashion is high.

Gosner and Black (1957) felt that acidity was a key factor and proposed that acid may act to alter "properties of the egg coats, interfering with normal osmotic control and responses to hatching enzymes." They also recognized that other physical or chemical factors in the water may be involved.

Saber and Dunson (1978) also felt that acidity was a major factor but noted high mortality of Bullfrog larvae in bog water of moderate pH and of brook trout embryos in neutralized bog water as evidence of a source of toxicity unrelated to pH. They suggested that humic acids may be involved since these compounds are known to have various deleterious properties and are present in bog water.

Our work also suggests that factors other than acidity <u>per se</u> may be involved. That the H_2SO_4/H_2O tests did not mimic the effects of bog water at similar pH suggests another factor. pH can apparently control the toxicity as the buffering tests indicated. We suggest that certain humic substances and pH operate in synergistic fashion to produce at least some of the observed effects. Since humic compounds are acidic in chemical character,it may be impossible to separate acidity from humic effects. Humic acids are phenolic compounds consisting of degraded tannin-protein-lignin-polysaccharide complexes (Swain 1978). It is these compounds that give bog water its dark color.

Tannins have extremely interesting properties; they are known to have the capacity to form cross-linked complexes with proteins that are resistant to proteolysis (protein breakdown) by enzymes (Van Sumere 1975). This has a potentially direct bearing on egg hatching. The amphibian egg usually consists of three jellylike layers surrounding the embryo. The embryo is immediately enclosed in the fertilization (vitelline) membrane. This membrane is secreted by the ovary; the jelly layers originate in the oviducts. The fertilization membrane is proteinaceous whereas the jelly layers are mucopolysaccharides (Salthe 1963). Tannins in bog water could effect the proteinaceous fertilization membrane making it resistant to enzymatic action. Enzymes secreted by the embryo are believed to break down the fertilization membrane and allow hatching to occur. Hence, amphibian eggs laid in bog water may be naturally "tanned". This may account for the coil condition in which the embryo develops but appears unable to hatch and dies within the egg. The tannins may have altered the properties of the egg membranes to make hatching impossible. Since the percentage of the coil condition varies between species with many embryos never reaching advanced stages, other processes are probably involved as well. As Gosner and Black suggest, osmotic problems may be very important.

We found no evidence to indicate that bog water whose pH had been artificially raised or was naturally moderate (> pH 4.5) produced lethal effects on amphibian embryos. Such water would still contain high levels of humic compounds. Hence, pH appears to be a controlling factor. Saber and

Dunson (1978), however, do report high mortality of Bullfrog embryos in bog water of pH 4.7-6.6 and of brook trout eggs in neutralized bog water. Such findings suggest that some species may be extremely sensitive to humic substances even in the absence of a pH "triggering mechanism".

If pH does act in a synergistic fashion with the humic substances in bog water,there is another important environmental factor to consider. Acid rain is a growing nationwide environmental problem (Gorham 1976). There is growing concern about its effects on the lakes and wetlands of northern Minnesota. Much of the water in peatland areas is already acidic to some degree. Acid rain could affect many areas by additionally lowering pH levels. If there is a pH/humic substance interaction,the toxic effect may be compounded. Many local areas,which now support a rich and abundant aquatic micro and macro flora and fauna,could be greatly altered by relatively slight pH changes with important consequences for the ecosystem.

The above discussion considers the mechanism of bog water toxicity. What is the ecological importance of this phenomenon? An environmental factor that can significantly reduce the reproductive success of an organism is clearly a potent selective pressure. A logical prediction based on the available information is that natural selection would over time eliminate breeding at these toxic sites.

Amphibians of various species have been shown to exhibit breeding site fidelity (i.e. they return to the same site each year). In areas where there is a mosaic of "good" and "bad" breeding sites, there would be strong selection for organisms that make the"correct" choice.

There might also be selection for recognition of environmental cues that are associated with the toxic sites. Odor might be such a cue. Amphibians of various species exhibit the ability to discriminate between different odors (Porter 1972). Even to a human observer a sphagnum bog water pool smells "different" than a fen pool.

However, in spite of such logical considerations, amphibians do breed at toxic bog water sites in unexpectedly large numbers (at least along Porter Ridge Road) considering the penalty involved. The Wood Frog, American Toad, and N. Spring Peeper were all heard calling from bog water sites. The calling implies breeding activity. Numerous egg masses of the Wood Frog and a lesser number of the American Toad were found (N. Spring Peeper eggs are extremely difficult to find). The Chorus Frog was occasionally heard. The N. Leopard Frog and Gray Tree Frog were never heard. Work to be done in 1980 will allow a more quantitative comparison of the utilization of toxic breeding sites in comparison with nontoxic sites by amphibians.

It has been suggested that bog water toxicity may play a role in determining the structure of amphibian communities in areas where this environmental factor is important (Gosner and Black 1957; Saber and Dunson 1978; and Janzen 1974). This is discussed in Sect. 4.2.6.

5.0 CONCLUDING REMARKS

Amphibians and reptiles are a fairly neglected and understudied group of animals. In large part this neglect is due to their general lack of human economic importance. Such a lack of importance on a human value scale is misleading. Numerous studies have demonstrated the important status of amphibians and reptiles in the natural economy (references in Porter 1972; Neill 1974). They are a particularly important component of wetland ecosystems. Amphibians, especially, are ideally suited to such areas. For the species that can deal with its various restrictions the peatlands provide choice habitat. Amphibians and reptiles undoubtedly constitute an important portion of the vertebrate biomass in these areas. Any disturbance affecting them would certainly have ramifications for many other species.

It would be premature to say anything specific about the effects of development on the peatlands herpetofauna. This report was not intended as an environmental impact statement. It is hoped that prior to any large-scale peatland development, if such development occurs, small-scale pilot development projects will allow true environmental impact studies to be made. These studies would consist of monitoring the area to be developed before, during, and after alteration. The research efforts of the various peatland ecology projects can serve as the foundation for such studies. It is hoped that they will be used in such a fashion.

Even before any major development occurs,the general conclusion is inescapable that the use of peat for large-scale energy purposes involving removal of the upper soil layer would have serious adverse consequences for all small resident animals such as amphibians, reptiles, and small mammals over the short term. Long-term effects would depend on the landscape rehabilitation programs adopted. The peatlands are a fragile and unique part of the natural heritage of Minnesota. It is hoped that areas of peatland large enough to preserve the intrinsic heterogeneity of these habitats will be kept as scenic and scientific reserves in spite of the pressures of development.

It is also felt that the toxic effects of bog water deserve further study. As pointed out in this paper, bog water is an exceedingly complex biochemical solution. If peatland development might result in the alteration of the water chemistry of the area,then more information is needed. We used amphibian embryos and larvae to assay toxicity. It is desirable to determine the effects on other species (plants and microorganisms as well as animals). Crawford (1978), Janzen (1974), and Swain (1978) have all pointed out potential toxicity problems associated with the chemical constituents of bog water. The elucidation of the potential problems associated with bog water is called for before the delicately balanced hydrologic setting of the peatlands is altered by development.

As pointed out in the report an additional environmental factor to be considered is acid rain. Acid rain is a growing concern in northern Minnesota; it could compound the toxicity effects found in habitats influenced by naturally acidic bog water.

The goal of this research program has been to provide basic background information on the relationship between amphibians and reptiles and the Minnesotan peatlands in the areas studied. Within the limitations of a two-year program this goal has been met. It has been a unique opportunity to study an interesting group of animals in a truly fascinating environment. It must be stressed, however, that the work done is by no means definitive. Two years is a relatively short period of time and has produced only a preliminary assessment of a relatively unexplored area. This work plus the other research programs will provide the foundation for future ecological research in the Minnesotan peatlands. It is to be hoped that this information will gain a deservedly wider audience through publication in the appropriate scientific journals.

ACKNOWLEDGEMENTS

We would like to thank Milt Stenlund, DNR Region II Administrator, and Chuck Spoken, Area Forest Manager, for permission to use the DNR Forestry facilities in Big Falls. This study would not have been possible without the use of these facilities.

In particular we would like to express appreciation for the assistance and friendship offered to us by the personnel of the Big Falls Forestry Station during the two 6 1/2 month field seasons. Many thanks to Ben Petz, Les Blakesly, John Lumpio, Jim Parker, and Bob Shaw.

We would also like to thank Barbara Coffin for aid in plant identification. Special thanks go to Gerda Nordquist and Mary Engelhard for aid in relevé field work and plant identification. Thanks also to Sue Madsen for aid in insect identification. Kevin Dickey, volunteer assistant for the 1978 season, was of invaluable help in the initial months of the study. Thanks to Norm Aaseng for valuable discussion, advice, and assistance.

We would especially like to thank Carol Gobar and Karen C. Karns for their patience, aid, and assistance without which this study could not have been completed.

LITERATURE CITED

Bury, R. B. 1977. Sampling herpetological communities by a removal method. Paper presented at the 1977 joint annual meeting of the Herpetologists' League--Society for the Study of Amph. and Rep.

Cobb, B. 1963. A Field Guide to the Ferns. Peterson Field Guide Series. Houghton Mifflin Co., Boston.

Conant, R. 1975. A Field Guide to Reptiles and Amphibians of Eastern and Central North America. 2nd Ed. Houghton Mifflin Co., Boston.

Crawford, R. L. 1978. Effects of peat utilization on water quality in Minnesota. Minnesota Department of Natural Resources.

Downs, F. 1978. Unisexual *Ambystoma* from the Bass islands of Lake Erie. Occas. Pap. Mus. Zool. Univ. Mich. No. 685:1-36.

Ewert, M. A. 1969. Seasonal Movements of the Toads Bufo americanus and B. cognatus in Northwestern Minnesota. Ph.D. Thesis, University of Minnesota.

Glaser, P. 1977. Terrestrial vegetation and wildlife supplement draft environmental impact statement. Minn. Power and Light Co.--Proposed Unit 4 (Clay Boswell steam electric station).--Appendix B-Vegetation.

Gleason, H. A., and Cronquist, A. 1963. Manual of Vascular Plants of Northeastern United States and Adjacent Canada. D. Van. Norstrand Co., N.Y.

Gorham, E. 1976. Acid precipitation and its influence upon aquatic ecosystems--an overview. Water, Air and Soil Pollution 6:457-481.

Gosner, K. L. 1960. A simplified table for staging anuran embryos and larvae. Herpetologica 16:183-190.

Gosner, K. L. and I. H. Black. 1957. The effects of acidity on the development and hatching of New Jersey frogs. Ecology 38(2):256-262.

Heinselman, M. L. 1963. Forest sites, bog processes, and peatland types in the Glacial Lake Agassiz Region, Minnesota. Ecol. Monogr. 33:327-374.

_______. 1970. Landscape evolution, peatland types, and the environment in the Lake Agassiz Peatlands Natural Area, Minnesota. Ecol. Monogr. 40:235-261.

Hodge, R. P. 1976. Amphibians and Reptiles in Alaska, the Yukon and Northwest Territories. Alaska Northwest Publishing Co., Anchorage, Alaska.

Janzen, D. H. 1974. Tropical blackwater rivers, animals, and mast fruiting in the Dipterocarpaceae. Biotropica 6(2):69-103.

Karns, D.R. and P. J. Regal. 1979. Relation of amphibians and reptiles to peatland habitats in Minnesota, Progress Report. In Minnesota Peat Program Progress Report No. 5. Minnesota Department of Natural Resources.

Morley, T. 1969. Spring Flora of Minnesota. Univ. of Minn. Press, Minneapolis.

Neill, W. T. 1974. Reptiles and Amphibians in the Service of Man. Indianapolis: Bobbs-Merrill.

Noble, G. K. and Noble, R. C. 1923. The Anderson tree frog, observations on its habits and life history. Zoologica. 2:417-455.

Porter, K. R. 1972. Herpetology. W. B. Saunders Co., Philadelphia.

Pough, F. H. 1976. Acid precipitation and embryonic mortality of spotted salamanders, Ambystoma maculatum. Science 192:68-70.

Pough, F. H. and R. E. Wilson. 1976. Acid precipitation and reproductive success of Ambystoma salamanders. In Proceedings of the 1st International Symposium on Acid Precipitation and the Forest Ecosystem. USDA Service General Tech. Report NE-23.

Rugh, R. 1941. Experimental Embryology: Techniques and Procedures. Burgess Publish. Co., Minneapolis.

Saber, P. A. and W. A. Dunson. 1978. Toxicity of bog water to embryonic and larval anuran amphibians. J. Exp. Zool. 204:33-42.

Salthe, S. N. 1963. The egg capsules in the Amphibia. J. Morph. 113:161-171.

Savage, R. M. 1961. The Ecology and Life History of the Common Frog. Sir Isaac Pitman & Sons, Ltd., London.

Schmidt, W. D. 1965. Aspects of the water economies of nine species of amphibians. Ecology 46(3):261-269.

Sjörs, H. 1950. On the relation between vegetation and electrolytes in North Swedish mire waters. Oikos 2:241-258.

Smith, H. M. 1978. A Guide to Field Identification: Amphibians of North America. Golden Press, N.Y.

Sokal, R. R. and Rohlf, F. J. 1969. Biometry. W. H. Freeman, San Francisco.

Stephan, C. E. 1975. Methods for Acute Toxicity Tests with Fish, Macroinvertebrates and Amphibians. EPA-660/3-75-009, April, 1975, Natl. Environ. Res. Center, Office of Res. and Dev., U. S. Environ. Protect. Agen., Corvallis Oregon.

Swain, T. 1978. Phenolics in the environment. In Biochemistry of Plant Phenolics. Ed. by T. Swain, J. B. Harborne, and C. F. Van Sumere. Plenum Press, N.Y. & London.

Van Sumere, C. F. 1975. In Chemistry and Biochemistry of Plant Proteins. Ed. by J. B. Harborne, Academic Press, London.

Voght, R. C. and R. L. Hine. 1977. Development and evaluation of techniques for assessment of impact of highway development on wildlife populations and habitats in the uppermidwest (Amphibians and Reptiles). Dept. Natl. Res., Madison, WI. In Press.

APPENDIX

HABITAT ANALYSIS

Table of Contents

1.0. Porter Ridge Bog

1.1. General information. In 1979 one restricted peatland area was studied intensively, the Porter Ridge Bog in central Koochiching County. This area is located in T154N, R25W, Sect. 31, 32, 33, 34; T153N, R25W, Sect. 6, 5, 4, 3, 2, 1, 10, 11, 12 of the Margie, and Big Falls SE Minnesota, Koochiching County quadrangles of the 1:24000 orthophotomaps (USGS). Porter Ridge is located about seven miles south of Big Falls to the east of Hwy 71. Big Falls is approximately 40 miles south of International Falls. Figure 1A is a map of Minnesota's peatlands showing the location of Porter Ridge Bog. Figure 2A is a map of the Porter Ridge Bog study area.

The peatlands of southern and central Koochiching County in which Porter Ridge is found are located in the southern portion of the eastern arm of ancient Lake Agassiz. Porter Ridge is a former beach of Lake Agassiz, formed as the lake slowly retreated at the end of the last Ice Age. In the poorly drained regions adjacent to the ridge typical water-saturated peatland habitats have evolved over the last 3000 years. An historical geological and floristic analysis of the general area can be found in Heinselman (1963, 1970).

Figure 2A indicates the major landforms and vegetational patterns found in the area of the ridge. The ridge is approximately six miles long and runs from the northwest to the southeast. Water flow is to the north. This appears to be a dominant factor in creating the patterns seen. The sandridge acts as a dam making conditions particularly wet to the south. The result is very stagnant black spruce raised bog forest to the south of the ridge. There are two major raised bog areas separated by a vegetationally variable black spruce/fen flowage area. Along the northern border of the two raised bog areas sharply delineated bog drains are found. Black spruce/sphagnum forest also lies to the north of the ridge,but it is of higher quality than the very stagnant black spruce forests to the south. The large mosaic of fen/swamp thicket found to the north of the ridge in section 33 appears to be related to the flowage between the two raised bog areas on the south "breaking through" the

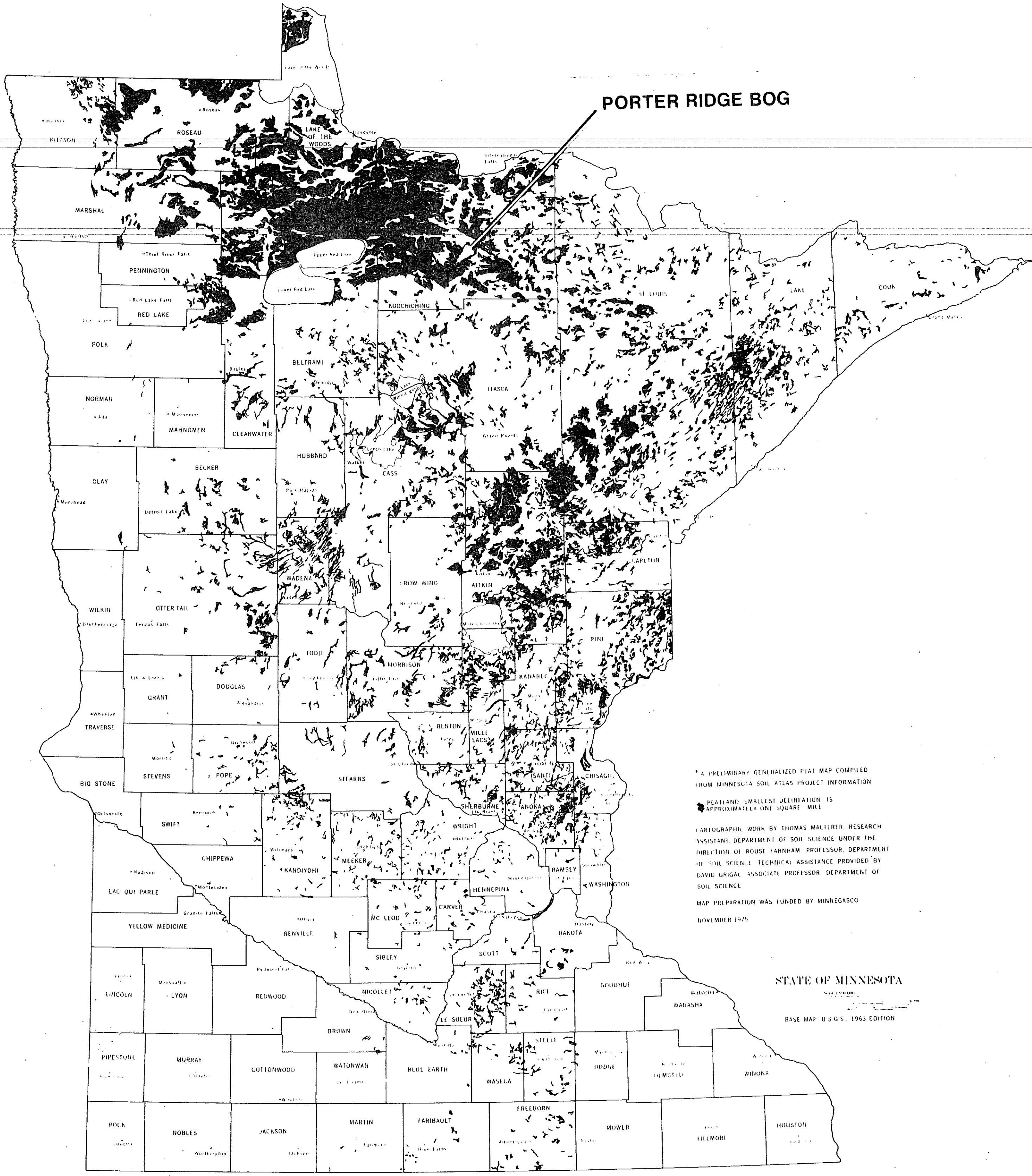


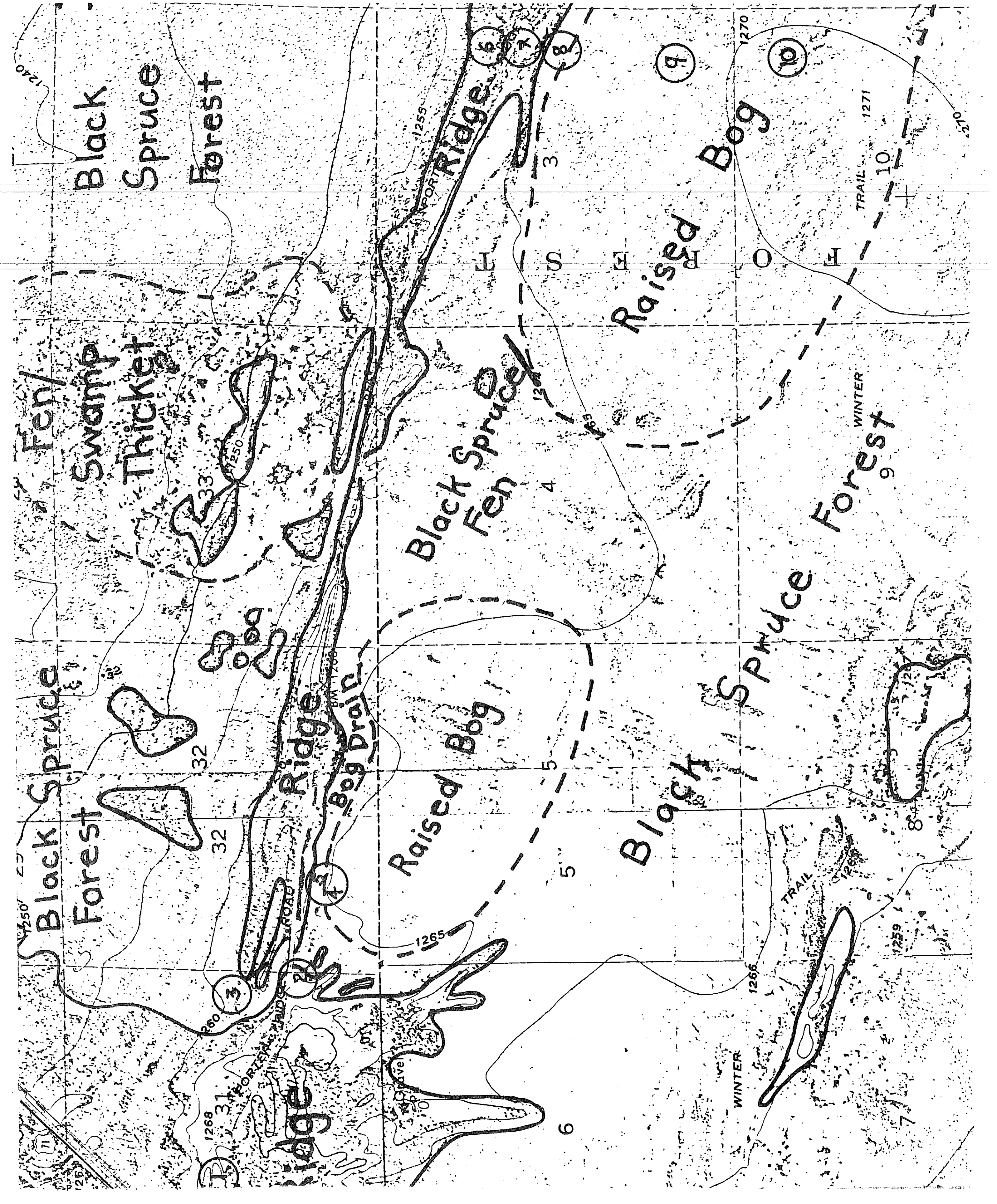
Figure 1A. Map of Minnesota showing the location of Porter Ridge Bog.

Figure 2A The Porter Ridge Bog study area map. Outlined areas delineate the upland sand soil Porter Ridge; other major landscape units are set off with dotted lines and/or labeled. Numbers depict trapping fence sites or important observation sites. The following list identifies the sites and indicates the appropriate habitat description or relevé to be consulted for more information.

1 = Ridge/Fen I (Habitat Description (HD) - A)
2 = Ridge/Fen II (HD-B)
3 = Ridge/Fen III (HD-C)
4 = Bog Drain I & II (HD-D)
5 = Wide Bog Drain (HD-E)
6 = Ridge I & II (Relevé A)
7 = Ridge/Fen IV (HD-F)
8 = Bog Drain III (Relevé B)
9 = Raised Bog I (Relevé C)
10 = Raised Bog II (Relevé C)

Note: Not all Porter Ridge Bog sites are shown on the map; Ridge/Fen Mosaic (HB-G) is located approximately one mile east of No. 7 along the southern edge of the ridge. The map shown is a xerox copy of portions of USGS orthophoto maps of the Margie and Big Falls SE, Koochiching County, quadrangles.

Figure 2A.


Black Spruce Forest
Fen/Swamp Thicket
Ridge
Raised Bog
Black Spruce/Black Spruce Fen
Black Spruce Forest
Black Spruce Forest
Ridge
Bog Drain
Raised Bog
Black Spruce Forest
Ridge
FOREST
TRAIL
WINTER
WINTER
TRAIL
ROAD
PORTER ROAD
Gravel
BM 1260
1240
1250
1255
1260
1265
1266
1268
1270
1271
1259
32
33
31
3
4
5
6
7
8
9
10

ridge. The ridge at this point is particularly narrow and floods out in the spring. Details of specific sites are given in the remainder of the Appendix.

The ridge is not a pristine site. There has been homesteading and logging along the ridge at various times. Logging continues today. Pine plantations have been planted at various sites. A major powerline is currently being put in to the north of the ridge. The bog to the south, however, due to its lack of commercial value has been largely undisturbed except for Christmas tree cutting.

2.0. Vegetation Analysis

2.1. Methods. There were eleven regularly visited sites at the Porter Ridge Bog area. Nine of these were trapping fence sites (13 fences total) and the remainder were important general observation sites. There were three main habitat types in the area: ridge/fen (i.e. upland), bog drain, and raised bog. I have presented complete relevés for only three sites; these sites were judged to be representative of the three major habitat types. This was done to avoid the redundancy of presenting numerous very similar relevés. For the remainder of the sites I have provided brief descriptions, which will convey the main features of that site in a telegraphic style.

Relevés were done following the general format described by Glaser (1977). The relevé key provides details of the system used. Locations refer to USGS Survey 1:24000 orthophoto quadrangle maps. Botanical nomenclature follows Gleason and Cronquist (1963), Cobb (1963), and Morley (1969).

RELEVÉ KEY

Height Classes

8 >35 m
7 20-35 m
6 10-20 m
5 5-10 m
4 2-5 m
3 0.5-2 m
2 0.1-0.5 m
1 <0.1 m

NOTE: After each species listed, three numbers appear. These refer to Coverage, Abundance, and Sociability of the plants listed, in that order. Under a given height class, species are listed in order of importance on the basis of these three factors.

Coverage

1 <5%
2 5-25%
3 25-50%
4 50-75%
5 >75%

Abundance

0 single occurrence
1 rare
2 few individuals
3 common
4 very numerous

Sociability

1 growing singly
2 grouped, few individuals
3 large group, many individuals
4 small colonies, extensive patches, broken mat
5 extensive mat

RELEVÉ A

RIDGE I & II (2 trapping fences)

DATE: July 9, 1979

LOCATION: Big Falls SE, Minn.: T153N, R25W, Sect. 3, NE quarter.

HABITAT: Upland mixed conifer-hardwood forest. Two trapping fences set at this site perpendicular to each other about 30m apart. Forest dominated by mature Quaking Aspen, Balsam Fir, and Paper Birch. Understory dominated by Beaked Hazel, Bracken Fern, Large-leaved Aster, and Bunchberry. Many fallen branches, much debris. Scattered open patches of essentially bare earth (5-25% of cover). Sandy soil. Site is typical of Porter Ridge's upland sandy ridge forest.

SAMPLE PLOT: 400 sq. m.

Height Class 6, cover 25-50%

- Populus tremuloides 2:2:1
- Abies balsamea 2:2:1

Height Class 5, cover 5-25%

- Betula papyrifera 1:2:1
- Abies balsamea 1:2:1

Height Class 4, cover 25-50%

- Amelanchier spp. 1:2:1
- Prunus spp. 1:2:1
- Populus tremuloides 2:3:1
- Abies balsamea 1:2:1
- Salix spp. 1:2:1

Height Class 3, cover > 75%

- Corylus cornuta 4:4:4
- Rosa spp. 1:2:1
- Abies balsamea 1:2:1
- Populus tremuloides 1:2:1
- Viburnum rafinesquianum 1:2:1
- Diervilla lonicera 1:2:1
- Prunus spp. 1:2:1
- Amelanchier spp. 1:2:1

Height Class 2, cover > 75%

- Pteridium aquilinum 4:4:1
- Aster macrophyllus 3:4:1
- Gramineae (broadleaf grasses) 2:3:1
- Diervilla lonicera 1:3:1
- Vaccinium spp. 1:2:1
- Rosa spp. 1:2:1
- Aralia nudicaulis 1:2:1
- Streptopus roseus 1:1:1
- Polygonatum pubescens 1:1:1
- Equisetum spp. 1:2:1
- Corylus cornuta 1:2:2
- Clintonia borealis 1:2:1
- Abies balsamea 1:2:1
- Maianthemum canadense 1:2:1
- Carex spp. (fine leaf) 1:1:1
- Populus tremuloides 1:2:1
- Fragaria virginiana 1:2:1
- Galium boreale 1:0:1

Height Class 1, cover 50-75%

- Cornus canadensis 2:4:1
- Lycopodium spp. 1:2:2
- Trientalis borealis 1:2:1
- Fragaria virginiana 1:2:1
- Maianthemum canadense 1:2:1
- Abies balsamea 1:2:1
- Vaccinium spp. 1:2:1
- Pyrola spp. 1:2:1
- Linnea borealis 1:2:1
- Coptis trifolia 1:2:1
- Neckera spp. (feathermoss) present

RELEVÉ B

Bog Drain II (1 trapping fence)

DATE: July 10, 1979

LOCATION: Big Falls SE, Minn.: T153N, R25W, Sect. 3, NE quarter.

HABITAT: Well canalized relatively narrow (≈ 75m) bog drain situated parallel to the oval upland open fen described in Ridge/Fen IV; separated from this fen by a strip (≈ 75m) of upland forest.

Distinct zonation across this area: main ridge-oval open fen-upland strip-bog drain-raised bog as one moves SW from Porter Ridge. Adjacent upland strip ends abruptly. Trapping fence located at edge of drain (southside) where tree cover begins to increase. Drain very open, almost treeless, with scattered stunted Black Spruce and Tamarack. Scattered large pools dominated by narrow sedges on ridge-side of fen (2-3 feet deep in spring), much floating sphagnum. Bog-side of drain continuous carpet of low relief sphagnum hummocks and hollows covered with ericaceous shrubs and cottongrass. Fades to the north into denser raised bog stagnant Black Spruce/sphagnum forest. Very wet site with standing water even during late summer dry periods. Sphagnum peat.

PEAT DEPTH: N-S transect across bog drain (going toward bog from ridge) = 23cm-79cm-114cm.

SAMPLE PLOT: 100 sq. m.

Height Class 4, cover < 5%

- *Picea mariana* 1:2:1
- *Larix laricina* 1:2:1

Height Class 3, cover 50-75%

- *Eriophorum* spp. 4:4:4
- *Picea mariana* 2:3:1

Height Class 2, cover 50-75%

- *Chamaedaphne calyculata* 3:4:4
- *Kalmia polifolia* 3:4:4
- *Andromeda glaucophylla* 1:2:1
- *Carex* spp. 2:3:1
- *Picea mariana* 1:2:1
- *Larix laricina* 1:0:1

Height Class 1, cover > 75%

- *Sphagnum* spp. 5:4:5
- *Vaccinium oxycoccos* 2:3:2
- *Chamaedaphne calyculata* 1:2:1
- *Kalmia polifolia* 1:2:1
- *Andromeda glaucophylla* 1:2:1
- *Polytrichum* spp. (under trees) 1:2:2

RELEVÉ C

RAISED BOG I & II (4 trapping fences)

DATE: July 10, 1979

LOCATION: Raised Bog I - Big Falls SE, Minn.: T153N, R25W, Sect. 3, SE quarter.
Raised Bog II - Big Falls SE, Minn.: T153N, R25W, Sect. 10, NE quarter.

HABITAT: Raised bog stagnant Black Spruce/sphagnum forest. Two pairs of trapping fences located in a large raised bog complex south of Porter Ridge. A winter trail provided easy access into the bog. Raised Bog I is located one half way down the winter trail (≈ .4 miles from the edge of the ridge). Deep Bog II is located at the end of the trail (≈ .8 miles from the ridge edge). Both sites are located ≈ 30m off the winter trail. Fences are perpendicular to each other ≈ 50m apart running parallel and perpendicular to the ridge. Forest completely dominated by stagnant Black Spruce with occasional Tamarack. Continuous carpet of relatively low relief sphagnum hummocks and hollows covered with ericaceous shrubs and cotton grass. The forb, Three-leaved False Solomon's Seal is also common. As is typical of raised bogs vegetational details vary over the general area. Black Spruce is denser and more robust at some sites fading into more open areas, some sites have a denser shrub understory, etc. Raised Bog I and II were very similar floristically hence one relevé (for Raised Bog I) is given. Raised Bog II had a somewhat denser ericaceous shrub cover and drier appearance. Wet sites with standing water in hollows except during dry periods. Sphagnum peat.

PEAT DEPTH: Raised Bog I = $\overline{X}$=180cm (range = 170-193cm).
Raised Bog II = $\overline{X}$=293cm (range = 272-312cm).

SAMPLE PLOT: 200 sq. m (Deep Bog I)

RAISED BOG I

Height Class 5, cover 5-25%

Picea mariana 2:4:1

Height Class 4, cover 5-25%

Picea mariana 2:4:1

Height Class 3, cover 5-25%

Picea mariana 2:3:1
Eriophorum spp. 1:2:1

Height Class 2, cover 50-75%

Ledum groenlandicum 3:4:4
Chamaedaphne calyculata 3:4:4
Kalmia polifolia 3:3:4
Picea mariana 1:2:1
Andromeda glaucophylla 1:2:1

Height Class 2, cover 50-75% (con'd)

Carex spp. 1:2:2
Vaccinium spp. 1:2:1
Salix spp. 1:1:1

Height Class 1, cover > 75%

Sphagnum spp. 5:4:5
Smilacina trifolia 4:4:1
Vaccinium vitis-idaea 2:3:4
Ledum groenlandicum 1:2:1
Chamaedaphne calyculata 1:2:1
Andromeda glaucophylla 1:2:1
Neckera spp. (present under trees)
Polytrichum spp. (present on tops of sphagnum hummocks)

HABITAT DESCRIPTION A

RIDGE/FEN I (1 trapping fence)

DATE: July 10, 1979

DESCRIPTION: Margie, Minn.: T154N, R25W, Sect. 31, NW quarter.

HABITAT: Small open fen (100m x 50m) bordered by upland forest to the south and Red Pine plantation to the north. Trapping fence is located in the upland forest ≈ 20m from the fen's edge. Upland forest dominated by mature Balsam Fir, Red Pine, and Jack Pine; some Quaking Aspen present. Understory dominated by Bracken Fern, Bunchberry and Blueberry. Forest is relatively open, parkland-like in appearance. Sandy soil. Fen/ridge border dominated by Iris and willows. Fen dominated by sedges, grasses, some reeds. Scattered clumps of bushy willow present. The fen is an extremely active amphibian breeding site in the spring. By August it is essentially dry.

HABITAT DESCRIPTION B

RIDGE/FEN II (1 trapping fence)

DATE: July 9, 1979

LOCATION: Margie, Minn.: T154N, R25W, Sect. 31, SE quarter.

HABITAT: Strip of upland forest bordering on a large open fen to the north and east. A Red Pine plantation is located on the ridge to the west. Trapping fence located in the upland forest ≈ 25m from the fen's edge. Forest dominated by Quaking Aspen. Understory dominated by Beaked Hazel and Bracken Fern. Wild Sarsaparilla, Large-leaved Aster, Strawberry and Blueberry also common. Sandy Soil. Ridge/fen border dominated by Alder, willow, Iris, sedges, cattails, and rushes. Adjacent open fen dominated by narrow and broad-leaved sedges, mostly narrow, with patches of cattails. To the south east the fen widens and joins the drainage of a large stagnant raised bog Black Spruce/sphagnum forest wtih resultant changes in floristics (see Bog Drain I & II, HABITAT DESCRIPTION D).

HABITAT DESCRIPTION C

RIDGE/FEN III (1 trapping fence)

DATE: July 9, 1979

LOCATION: Margie, Minn.: T154N, R25W, Sect. 32, SW quarter.

HABITAT: Peninsula of upland forest bordered by open sedge fen to the south and swampy lowland brush to the north. Trapping fence located in forest ≈ 20m north of the fen. Forest dominated by mature Quaking Aspen. Understory dominated by Beaked Hazel and Bracken Fern. Horsetails, medium-width sedges, Large-leaved Aster, and Wild Sarsaparilla also common. Sandy loam soil. Fairly low site, very wet in the spring. Ridge/fen border dominated by willow, Alder, Iris, and sedges. Adjacent fen dominated by narrow and broad-leaved sedges, with patches of cattails. Fen is active amphibian breeding site in the spring.

HABITAT DESCRIPTION D

BOG DRAIN I & II (2 trapping fences)

DATE: July 10, 1979

LOCATION: Margie, Minn.: T154N, R25W, Sect. 32, SW quarter.

HABITAT: Raised bog stagnant Black Spruce Forest. Forest separated from Porter Ridge to the north by a clearly defined bog drain (see Wide Bog Drain, HABITAT DESCRIPTION E). Two trapping fences located ≈ 100m apart, ≈ 25m from the edge of the drain. Typical stagnant Black Spruce/sphagnum forest dominated completely by stunted Black Spruce, occasional Tamarack seen. Understory dominated by Labrador Tea, Leatherleaf, Bog Rosemary, Laurel, and Cottongrass tussocks. Blueberry and Pitcher Plants also common. Few sedges. Substrate is typical low relief carpet of sphagnum hummocks and hollows. Sphagnum peat soil. Very wet site with standing water in depressions during wet periods. Water table obviously near surface.

PEAT DEPTH: Bog Drain I = 160cm (range 155-165cm).
Bog Drain II = 165cm (range 160-170cm).

HABITAT DESCRIPTION E

WIDE BOG DRAIN

DATE: 9 July 1979

LOCATION: Margie, Minn.: T154N, R25W, Sect. 32, SW quarter.

HABITAT: Well canalized bog drain ≈ 200m across (at this point). Separates Porter Ridge to the north from raised bog stagnant Black Spruce (see Bog Drain I & II, HABITAT DESCRIPTION D) to the south. Jack Pine and Blue Spruce plantations on adjacent ridge. Clear zonation across the drain. Border zone of willow, Iris, Reedgrass, and Feathermoss on ridge side (north). Fades into sedge dominated open fen with scattered island like sphagnum hummocks crowned with Leatherleaf to the south. Continuous carpet of floating sphagnum in H_2O. Large patches of Scheuchzeria as bog is approached. Near bog, narrow zone of sphagnum hummocks with ericaceous shrubs, Cottongrass tussocks, very stunted Black Spruce, and Tamarack fading into denser Black Spruce bog forest. Sphagnum-sedge peat. Extremely wet area which drains the bog complex to the south. Waterflow is to the north. Standing water in spring is 1-2 feet deep in central drain. Fairly active amphibian breeding site in spring.

PEAT DEPTH: N-S Transect across bog drain (going toward bog from ridge) = 33cm-51cm-76cm.

HABITAT DESCRIPTION F

RIDGE/FEN IV (1 trapping fence)

DATE: July 9, 1979

LOCATION: Big Falls SE, Minn.: T153N, R25W, Sect. 3, NE quarter.

HABITAT: Oval shaped open fen ($\approx$ 1200m long, $\approx$ 75m wide) which parallels Porter Ridge. Bordered on the north by the main body of the ridge and to the south by a relatively narrow ($\approx$ 75m) strip of upland forest. To the south of this narrow strip is a narrow bog drain fading into raised bog stagnant Black Spruce forest (see Bog Drain III, RELEVÉ B). A trapping fence site is located on the north side of the fen near the western end. The upland forest on both sides of the fen is dominated by Balsam Fir, Paper Birch, Jack Pine, and Quaking Aspen. The understory is dominated by Beaked Hazel, Bracken Fern, small Balsam Fir, and Wild Sarsaparilla. The fen is bordered by willow, Alder and young Quaking Aspen. Fen dominated by coarse sedges, scattered willows, and patches of cattails. Marsh Cinquefoil common under sedges. Ridge adjacent to fen with sandy soil. Fen with sedge peat. Fen is very wet site with standing water even during late summer dry periods. Fen is very active amphibian breeding site in spring.

PEAT DEPTH: N-S transect across fen = 65cm-91cm-69cm.

HABITAT DESCRIPTION G

RIDGE/FEN MOSAIC

DATE:	July 9, 1979
LOCATION:	Big Falls SE: Minn.: T153N, R25W, Sect. 2, SE quarter.
HABITAT:	Open fen upland mosaic on southern edge of Porter Ridge. Small fens surrounded by pine plantations and clumps of Black Spruce, Jack Pine, and Quaking Aspen. Fens with tall graminoid layer of sedges, grasses and reeds. Iris and horsetails present. Sphagnum and Dicranum are common mosses. Scattered clumps of willow. Bordered by Porter Ridge Road on the north. To south of fen/upland mosaic sharp zonation with a Quaking Aspen, Willow, Jack Pine, Black Spruce border fading abruptly into open bog drain with large open pools of water, fine-leaved sedges, and sphagnum mounds crowned with Leatherleaf. This in turn fades into stagnant raised bog Black Spruce/sphagnum forest. Fen is very active amphibian breeding site in the spring. Very wet sites in spring with much standing water gradually drying out as season progresses. Bog drain remains very wet all season.

HABITAT DESCRIPTION H

UPLAND BREEDING SITES

DATE:	July 11, 1979
LOCATION:	Scattered sites in the general area of Big Falls, Koochiching County, Minn.
HABITAT:	Roadside ditches and non-peat upland pools. These sites were located near Big Falls and were extremely active breeding sites typical of non-peatland habitats. Roadside ditches bordered by willows and adjacent Quaking Aspen groves. Ditch dominated by sedges, grasses, reeds, cattails. Upland pools dominated by willows, cattails, coarse sedges, and grasses. Rich minerotrophic sites, with clay substrates, and alkaline water. Ditches and pools with standing water through most of season depending on site.

Table 2A. Monthly substrate temperature (^{o}C) measurements at five Porter Ridge Bog sites: April-October, 1979. Substrate temperatures were taken in the sun and shade each time a site was visited. The mean max/min and range of temperatures found is given for each site for each month. See Sect. 2.4.2. and 4.2.2. for details. See Appendix for locations and descriptions of sites.

Substrate Temp. °C / Month	April	May	June	July	Aug	Sept	Oct
Ridge Fen II							
$\bar{X}$ Max, (Range)	3.9(0.4-10.0)	15.0(5.8-32.0)	21.3(16.0-30.8)	23.5(17.0-29.0)	23.6(21.0-28.5)	18.7(12.8-21.0)	9.8(8.0-11.5)
$\bar{X}$ Min, (Range)	3.1(0.2-7.0)	8.8(4.5-15.0)	14.8(14.0-15.5)	19.5(16.5-22.0)	18.3(15.0-21.0)	16.5(10.0-20.0)	9.2(7.8-10.5)
Bog Drain I							
$\bar{X}$ Max, (Range)	3.8(1.0-10.0)	15.8(5.5-30.0)	22.5(14.0-31.0)	30.3(27.0-37.0)	28.0(21.0-32.0)	22.3(11.0-28.0)	8.5(7.0-10.0)
$\bar{X}$ Min, (Range)	0.6(0.2-1.0)	1.6(0.4-3.0)	5.8(5.0-6.5)	14.1(13.0-16.0)	15.0(14.0-15.8)	13.3(10.5-15.0)	7.8(6.8-8.8)
Ridge I							
$\bar{X}$ Max, (Range)	---	---	---	22.8(22.0-31.0)	17.5(14.0-22.0)	13.0(11.0-15.0)	4.3(3.5-5.0)
$\bar{X}$ Min, (Range)	---	---	---	19.1(18.5-22.0)	14.4(11.0-17.5)	11.7(9.8-14.5)	3.3(2.5-4.0)
Bog Drain III							
$\bar{X}$ Max, (Range)	---	---	---	30.8(26.0-38.0)	25.1(18.0-34.0)	14.8(12.2-18.0)	6.4(6.0-6.8)
$\bar{X}$ Min, (Range)	---	---	---	20.5(16.0-24.0)	15.3(13.0-17.2)	12.5(0.5-15.0)	5.3(4.5-6.0)
Raised Bog I							
$\bar{X}$ Max, (Range)	---	---	---	31.3(28.0-36.0)	23.5(17.0-36.0)	14.5(13.0-17.0)	6.5(6.5)
$\bar{X}$ Min, (Range)	---	---	---	22.0(19.0-26.0)	13.5(11.0-15.5)	12.2(11.0-13.2)	4.8(4.0-5.5)

Table 2A. Legend on preceding page.

Big Falls 1978	April	May	June	July	Aug	Sept	Oct
Temp(^{o}C) $\overline{X}$ Max, (Range)	12.2(-1.1-23.3)	23.4(12.2-31.1)	25.0(14.4-32.8)	26.6(22.2-31.7)	27.2(17.8-34.4)	19.8(11.1-33.9)	14.4(5.6-25.6)
Temp(^{o}C) $\overline{X}$ Min, (Range)	-2.7(-8.9-4.4)	5.2(-5.6-16.1)	8.1(-1.7-13.9)	11.3(5.0-15.6)	10.4(3.3-21.1)	8.5(0.0-19.4)	0.6(7.8-10.6)
Precipitation(cm)	3.5	9.0	4.8	14.5	14.8	8.6	1.1
Big Falls 1979							
Temp(^{o}C) $\overline{X}$ Max, (Range)	10.0(-0.6-21.1)	13.8(3.3-28.9)	23.9(16.1-28.3)	26.7(17.8-32.2)	23.9(18.3-29.4)	21.7(14.4-31.1)	---
Temp(^{o}C) $\overline{X}$ Min, (Range)	-3.8(-14.4-3.3)	1.6(-3.9-13.3)	7.2(0.0-17.8)	11.1(4.4-16.7)	8.3(0.0-13.9)	5.6(-1.1-17.8)	---
Precipitation(cm)	2.0	5.1	15.4	8.8	3.7	2.9	---

Table 3A. Monthly temperature (^{o}C) and precipitation (cm) data: Big Falls, Minnesota, April-October 1978, 1979. Data compiled from measurements taken at the Big Falls Forestry Station, Big Falls, Koochiching County. Mean monthly max/min temperatures and ranges and total monthly rainfall are given.