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GRADUATE COLLEGE

ETHOECOLOGY OF SCAPHIOPUS (PELOBATIDAE) LARVAE IN TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

A DISSERTATION

SUBMITTED TO THE GRADUATE FACULTY

in partial fulfillment of the requirements for the

degree of

DOCTOR OF PHILOSOPHY

BY

JEFFREY HOWARD BLACK

Norman, Oklahoma

1973

ETHOECOLOGY OF *SCAPHIOPUS* (PELOBATIDAE) LARVAE IN TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

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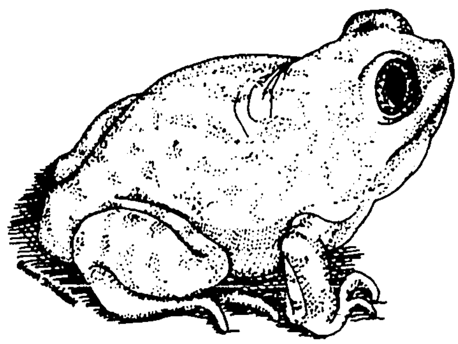

During the better part of the last
20 years or so, I have studied diligently
all species of the Amphibia in Oklahoma
(about 50 kinds), and of them all none
are so surprising as the spadefoots.
Scarcely a year passes that some new
phenomenon in one species or another of
them does not show up. And, still, just
as I think that now (at last!) I have
finally solved the mystery of their life
story, I find some that quite obviously
have not read my scientific papers!
They just do not behave as I had supposed,
and I have to start all over again.

ARTHUR N. BRAGG

Reprinted by permission from Gnomes of the Night; The Spadefoot Toads, University of Pennsylvania Press, Philadelphia, Pennsylvania, 1965.

DR. ARTHUR NORRIS BRAGG

18 December 1897 - 27 August 1968

When I am forgotten, as I shall be,
And sleep in dull cold marble
****
Say, I taught thee.
-Henry VIII, Act III, Sc. 2, L. 433

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This dissertation is dedicated to the late Dr. Arthur N. Bragg and his wife, Mary Bragg. Dr. Bragg served as my major professor until his death in August, 1968, and during that year, through many hours of discussion and trips throughout Oklahoma, he unveiled to me the mysterious world of his "Gnomes of the Night", the spadefoot toads. Mary Bragg has been one of my family's dearest friends and supporter. During this research she was always there to offer her encouragement.

I am very grateful to Dr. Charles C. Carpenter who has served as my major professor since Dr. Bragg's death. He has patiently and diligently encouraged me toward completion of this dissertation and his knowledge of many aspects of zoology and his own dedication to research have set an attitude for my scholastic endeavor.

Dr. Howard P. Clemens receives my appreciation for his help and guidance in bringing this paper to a climax. His "brain-storming" sessions revealed the ways to analyze limnological data, and the importance of a person studying amphibian larval ecology to also have a knowledge of fish culture.

I also wish to thank the following members of my committee for the help and counsel they have extended during the preparation of this dissertation: Dr. Andrew Robertson, Dr. George Goodman and Dr. J. K. Greer.

I wish to express my appreciation to Mr. and Mrs. Carl Burrows for phoning me whenever it rained near Tipton, and for their many courtesies during my trips to Tipton. They are those rare people who will awaken at all hours of the night to listen for the call of the spadefoots in order to help a graduate student.

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It is a rare wife that will live with a house full of tadpoles and boiling lettuce and I give a very special thanks to my wife Judith. Not only has she assisted with research and this dissertation, but also offered continual encouragement and support.

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ETHOECOLOGY OF SCAPHIOPUS (PELOBATIDAE) LARVAE IN TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

CHAPTER I

INTRODUCTION

Spadefoot toads are interesting because of their secretive habits, adaptations to xeric environments, formation of large breeding aggregations during periods of heavy rainfall, and the developmental and aggregational behavior of their larvae.

The most important publications dealing with the genus *Scaphiopus* are those from 1940 through 1969 of the late Arthur N. Bragg of The University of Oklahoma. In addition to Ball (1936), Brown (1967a, 1967b), Gilmore (1924), Hansen (1958, 1965), Liner (1966), McClanahan (1967), Mayhew (1965), Neill (1957), Pearson (1955, 1957), Richmond (1947), Tanner (1936), Shoemaker, McClanahan and Ruibal (1969), Wasserman (1957 through 1970), and Zweifel (1956), numerous other publications have contributed to the knowledge of spadefoot ecology.

This study is the first to characterize the ecological habitat of *Scaphiopus* larvae and describe some of the behavioral mechanisms involved in the formation of larval aggregations, schools and pods.

The physico-chemical features of temporary pool waters where *Scaphiopus* larvae develop were examined as well as associated invertebrates, vertebrates and plants.

I will use the term temporary pool to designate any small shallow body of water that usually contains water during one or more periods of the year and is subjected to periodic drying during the year.

CHAPTER II

TAXONOMY AND OKLAHOMA DISTRIBUTION

The spadefoot toads of the genus *Scaphiopus* are an exclusive North American group of Anura. In most parts of the United States, at least one species of spadefoot occurs. Only one of them, the Mexican Spadefoot, does not occur in the United States.

The taxonomic and phylogenetic relationships of the genus *Scaphiopus* are still in much confusion. Older works place them in the Old World family Pelobatidae and Zweifel (1956) has reported that the North American spadefoot toads are of northern origin and did not arise in the southwestern parts of North American independently of the European and extinct Asiatic forms. Most other authorities such as Stebbins (1951, 1954) and Bragg (1965b) also agree. The number of genera is also uncertain. Cope (1889) recognized two: (1) *Scaphiopus* and (2) *Spea*. Tanner (1939) applied Cope's *Spea* to four of the forms (considered as a subgenus) and Bragg (1965b), Stebbins (1951), and Zweifel (1956) have also used this as differentiating between the two different species groups.

There is similar confusion as to how the eight or nine forms should be classified as to species or subspecies. There is need for a thorough revision of the genus *Scaphiopus*. I will follow the scheme of A. N. Bragg from his unpublished manuscript on "The Toads and Frogs of Oklahoma with

Emphasis on their Habits", and his book *Gnomes of the Night* (1965).

Class Amphibia

Order Salientia (Anura)

Family Pelobatidae

Subgenus *Scaphiopus*

1. *Scaphiopus* (*Scaphiopus*) holbrooki holbrooki (Harlan)

   (Eastern Spadefoot)

2. *Scaphiopus* (*Scaphiopus*) *holbrooki* *hurteri* Strecker

   (Hurter's Spadefoot)

3. *Scaphiopus* (*Scaphiopus*) *couchi* Baird

   (Couch's Spadefoot)

Subgenus *Spea*

1. *Scaphiopus* (*Spea*) *bombifrons* Cope

   (Plains Spadefoot)

2. *Scaphiopus* (*Spea*) *multiplicatus* Cope

   (Mexican Spadefoot)

3. *Scaphiopus* (*Spea*) *hammondi* *hammondi* Baird

   (Hammond's Spadefoot)

4. *Scaphiopus* (*Spea*) *hammondi* *intermontanus* Cope

   (Great Basin Spadefoot)

Oklahoma has four spadefoots, *S. couchi*, *S. h. hurteri*, *S. bombifrons*, and *S. h. hammondi.* In Oklahoma, *S. couchi* is known only from the short-grass - mesquite region of southwestern Oklahoma. *S. bombifrons* is abundant over the western half of Oklahoma with scattered records east to

Tulsa and Muskogee Counties. *S. h. hammondi* is known in Oklahoma from Woods County and probably occurs in Harper County and throughout the Oklahoma Panhandle. *S. h. hurteri* is characteristic of eastern Oklahoma where it occurs in the oak-hickory savanna. My study was concerned with the more common *S. couchi*, *S. bombifrons*, and *S. h. hurteri*.

CHAPTER III

DESCRIPTION OF THE STUDY AREAS

Introduction

During the spring and summer of 1968, the late Dr. Bragg showed me many of the temporary pools in Oklahoma used by *S. bombifrons*, *S. couchi* and *S. h. hurteri* for breeding and where he had observed aggregational behavior in *Scaphiopus* larvae.

Pools were chosen in Tillman County for studying *S. bombifrons* and *S. couchi*, and in Cleveland and Pottawatomie Counties for studying *S. h. hurteri*.

Methods

Climatological information and data on these counties was obtained from the National Records Center, Ashville, North Carolina, and from Vernon J. Frye, Cleveland County Agent, and Laxton Malcom, Tillman County Agent.

Legal descriptions were obtained from Geologic Maps purchased from the Oklahoma Geological Survey, Norman, Oklahoma.

Results

Climatological Data

Tillman County is in southwestern Oklahoma and is characterized by mild, short winters and long hot summers. Below zero temperatures are rare, having occurred on only 10 days in a period of 38 years. Temperatures of 32 C or higher have been observed in every month except December and temperatures of 38 C or higher occur on an average of 40 days each summer.

Rainfall in Tipton which contains several of the study pools, averages 26 inches with the greater amounts occurring in spring and fall. Dry spells of varying intensities associated with the climate of the Southwestern Great Plains materially affect the formation of temporary pools as well as agriculture in Tillman County.

Rainfall amounts for 1969 and 1970 during my study period in Tillman County are shown in Table 1.

Table 1. Total monthly rainfall (in inches) during 1969 and 1970 in Tipton, Tillman County, Oklahoma.

	1969	1970
January	0.26	0.06
February	2.01	0.39
March	1.88	3.66
April	0.81	1.20
May	4.84	2.24
June	1.49	0.67
July	2.04	0.00
August	3.20	0.76
September	4.11	2.46
October	0.47	1.54
November	0.42	0.23
December	0.20	0.25
Total Moisture	21.73	13.46

From 1969 through 1972, there has been an increasing drought in Tillman County.

According to Bruner (1931), rainfall decreases westward in Oklahoma at the approximate rate of one inch for each twenty miles. Furthermore the rainfall becomes more torrential westward and less evenly distributed throughout the year. As a result, the conditions are progressively unfavorable for forest development. This is certainly true in my study area where the only evident trees are in the town of Tipton, around farm houses, or along the Red River.

Tillman County is called part of the *Stipa-Koeleria* association by Bruner (1931). This is a true prairie with hosts of legumes, composites, and evening primroses. Only trees of the earliest stages in the development of flood-plain forests occur; these are primarily the willows (*Salix sp.*) and the western cottonwood (*Populus deltoides*).

Bruner (1931) considered Tillman County as part of the Redbud Plains with fine soils well suited to the growth of grasses which still dominate in the non-agricultural areas of the county.

Cleveland and Pottawatomie Counties are both located in central Oklahoma.

Research pools were located 5.5 and 15.5 miles east of Norman, Cleveland County, and 22.5 miles east of Norman, Pottawatomie County. No weather stations are located near these pools. The climatic conditions of Norman, Cleveland County, are quite similar to those found at the research pools.

Central Oklahoma is an area of continental climatic conditions with both circumdiel and seasonal climatic changes often being quite large. The winters are fairly mild with an average January temperature at Norman of 4.7 C. The highest temperatures occur in July and August; the lowest in December, January and February. There are usually several periods of a few days or more with cold freezing weather. The summers are warm with an average July temperature at Norman of 28.2 C. Average annual rainfall is 33.95 inches, which includes an average snowfall of 5.2 inches, occurring primarily in January and February. The months with the highest precipitation are May and June. Central Oklahoma is rather windy with strong winds occurring frequently in all seasons.

Research pools are located in small grassy openings in the oak-hickory forest. These pools would be described as occurring in the oak-hickory savanna of the Southern Plains by Rice and Penfound (1959) and Bruner (1931). It has also been called the dominant woodland by Penfound (1962). Common trees surrounding the pools are blackjack oak (*Quercus marilandica*) and post oak (*Quercus stellata*). Both of these trees rarely exceed 40 feet in the oak-hickory savanna (Rice and Penfound, 1959). This area is characterized by varying degrees of dominance of woodland and grassland and is essentially a transition community between forest and prairie but its extent and character are controlled by the sandy texture of the soil. Physiographic maps indicate that these research pools are located in the Redbed Plains and Sandstone Hills.

Physical Description and Location of Study Pools

Over thirty temporary pools were studied periodically during 1968 through 1971. Of these pools, only about seven were subjected to extensive studies.

1. Pool 1. This is Pool A of Bragg (1944b, 1945b, and 1950) and is pictured in Bragg (1950e, Fig. 16, pg. 95). It is located about 5.5 miles east of Norman on Alameda Street, Cleveland County. Morphometric data are given in Table 2 and a contour map in Figure 1. Legal description: SW¼ SE¼ Section 29, T.9N., R.1W.

2. Pool 2. This is Pool D of Bragg (1945b, 1957b) and is pictured in Bragg (1950e, Fig. 19, pg. 97). It is located about 15.5 miles east of Norman on the north side of Highway 9, Cleveland County. Morphometric data are given in Table 2 and a contour map in Figure 2. Legal description: SE¼ SE¼ Section 22, T.9N., R.1E.

3. Pool 3. This is Pool P_1 of Bragg (1964b). It is about 22.5 miles east of Norman on the north side of Highway 9, Pottawatomie County. Morphometric data are given in Table 2 and a contour map in Figure 3. Legal description: SE¼ SE¼ Section 9, T.9N., R.2E.

4. Pool 4. This is a temporary pool one half mile northwest of the Oliver Wildlife Preserve on the John Potts Farm, Cleveland County. It was located in a cultivated field inside the city limits of Norman and was destroyed by highway construction in 1970. Legal description: NW¼ NE¼ SW¼ Section 7, T.8N., R.3W.

5. Pool 5. This is a temporary pool one half mile northwest of the Oliver Wildlife Preserve on the John Potts Farm, Cleveland County. This pool is inside the city limits of Norman in a cultivated field, and is about 90 feet east of Pool 4. It is periodically destroyed by cultivation but usually reforms. Legal description: NW¼ NE¼ SW¼ Section 7, T.8N., R.3W.

Table 2. Geographic location and morphometric data for the basins of Pool 1 and Pool 2, Cleveland County, and Pool 3, Pottawatomie County.

	Pool 1	Pool 2	Pool 3
Location	SW¼, SE¼, Sec. 29, T.9N., R.1W., Cleveland Co.	SE¼, SE¼, Sec. 22, T.9N., R.1E., Cleveland Co.	SE¼, SE¼, Sec. 9, T.9N., R.2E., Pottawatomie Co.
Maximum length (m)	32.1	31.8	10.8
Maximum effective length (m)	29.7	31.8	10.8
Maximum width (m)	5.4	9.3	8.9
Maximum effective width (m)	5.4	9.3	8.9
Maximum depth (cm)	27.0	30.0	23.0
Mean depth (cm)	13.1	14.9	5.9
Surface area (m^2)	126.0	189.0	139.0
Volume (m^3)	1645.0	2813.0	811.0
Length of shoreline (m)	69.3	71.0	30.3

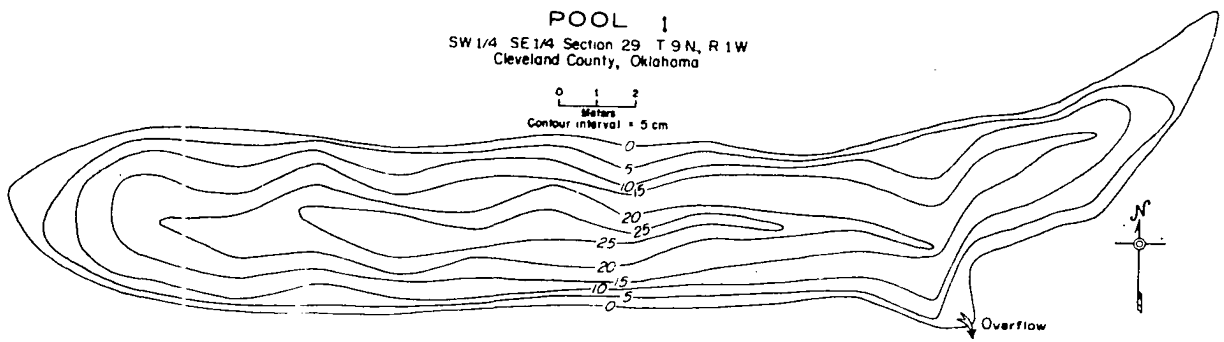


Figure 1. Contour map of Pool 1, Cleveland County, Oklahoma.

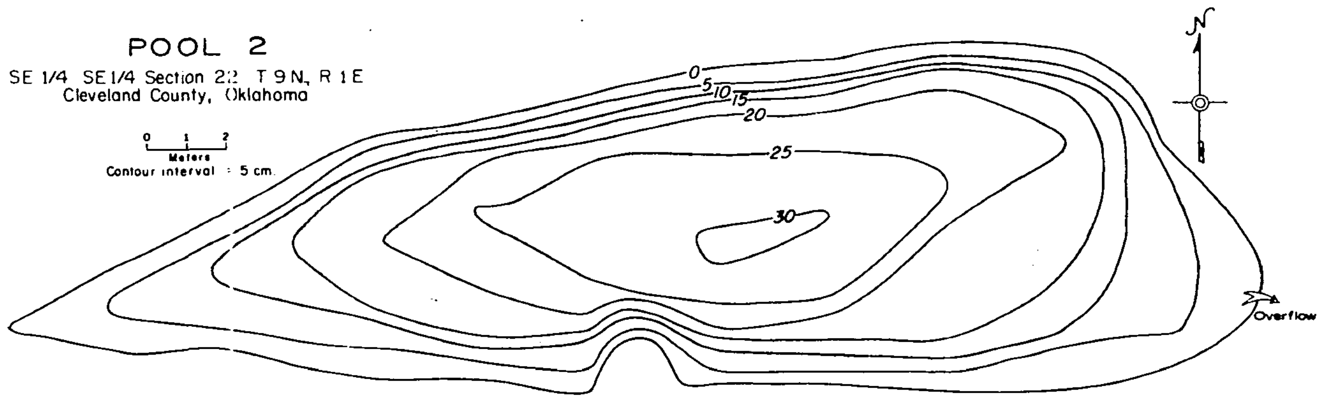


Figure 2. Contour map of Pool 2, Cleveland County, Oklahoma.

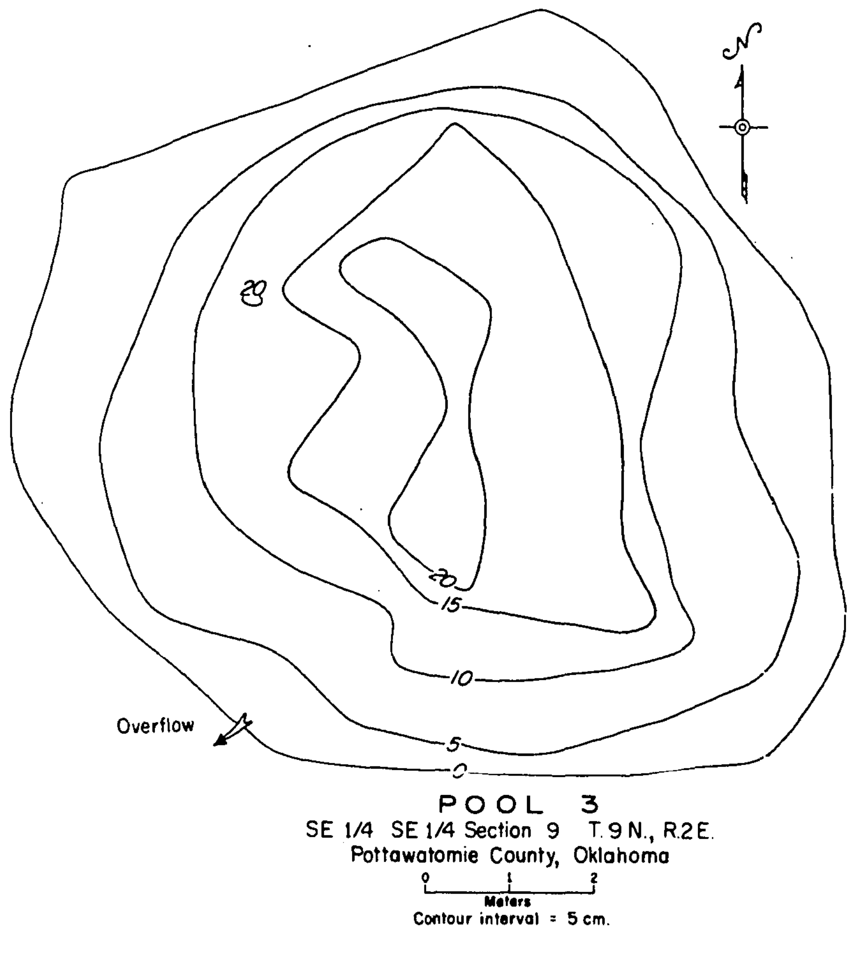


Figure 3. Contour map of Pool 3, Pottawatomie County, Oklahoma.

6. Little Axe Pool 6. This is a very small pool formed by water erosion from adjacent Little Axe Pool 7. After hard rains, Little Axe Pool 7 fills with water which then runs over a bank into Little Axe Pool 6. It is about 1 meter in diameter and one mile east of Little Axe, Cleveland County. Legal description: SE¼ SE¼ Section 21, T.9N., R.1E.

7. Little Axe Pool 7. This is a shallow pool about 15 m long and 5 m wide that fills with water for only a few hours after heavy rains and then the complete pool drains into Little Axe Pool 6 and then into a drainage ditch. It lies northwest of Little Axe Pool 6 and is one mile east of Little Axe, Cleveland County. Legal description: SE¼ SE¼ Section 21, T.9N., R.1E.

8. Little Axe Pool 8. This is a roadside depression on the south side of State Highway 9, one mile east of Little Axe, Cleveland County. It is about 6 m long and 1.2 m wide. Legal description: NW¼ NW¼ Section 27, T.9N., R.1E.

9. Pool 9. This is Pool F of Bragg (1944b, 1945b, 1948a, 1950e). It is located about 15.5 miles east of Norman, Cleveland County, and is 300 feet northeast of Pool 2 and Highway 9. It measures about 11 m long and 1.2 m wide. Legal description: SE¼ SE¼ Section 22, T.9N., R.1E.

10. Power Station Pool. This is a roadside ditch about 1.5 miles west of Tipton, Tillman County. It is on the north side of Highway 5 and runs north and south on the east side of section dirt road. A cross section of this pool is shown in Figure 4; the pool is 48 m long, 2.7 m wide and 45 cm deep. Legal description: SE¼ SE¼ SE¼ Section 35, T.1N., R.19W.

11. Pool 11. This is a roadside ditch on the north side of Highway 5, 0.7 miles west of Tipton, Tillman County. It runs east to west and is about 35 m long and 3 m wide when filled. Legal description: SW¼ SE¼ Section 35, T.1N., R.19W.

12. Pool 12. This is a roadside depression on the south side of Highway 5, 0.7 miles west of Tipton, Tillman County. It is about 35 m long and 3.5 m wide and runs in an east to west direction. It is frequently filled from irrigation of an adjacent field. Legal description: NE¼ NW¼ NW¼ Section 2, T.1S., R.19W.

13. Pool 13. This pool is a depression in a cultivated field on the south side of Highway 5, 0.25 miles west of Tipton, Tillman County. It formed only once during this study. Legal description: NW¼ NW¼ NE¼ Section 2, T.1S., R.19W.

14. Pool 14. This pool is a depression in a cultivated field on the south side of Highway 5, 0.5 miles west of Tipton, Tillman County. It runs in a north to south direction and covers over an acre when completely filled. It formed only once during my study. Legal description: E½ NE¼ NW¼ Section 2, T.1S., R.19W.

15. Pool 15. This is a roadside ditch on the south side of Highway 5, 0.25 miles west of Tipton, Tillman County. It stretches for over 675 m in an east to west direction and is over 5 m wide and up to 1 meter in depth when completely filled. It can contain water for several months at a time. A cross section of this pool is in Figure 4. Legal description: N½ NW¼ NE¼ Section 2, T.1S., R.19W.

16. Pool 16. This is a roadside ditch on the north side of Highway 5, 0.3 miles west of Tipton, Tillman County. It stretches east to west

for over 470 m and is 4.3 m wide and up to 40 cm deep. A cross section of this pool is in Figure 4. Legal description: S½ SW¼ SW¼ Section 36, T.1N., R.19W.

17. Pool 17. This is a roadside ditch along a dirt road about 0.5 miles west of Tipton, Tillman County. It runs in a north to south direction perpendicular to Highway 5 and on the east side of the dirt road. It is 104 m long, 4.3 m wide and over 28 cm deep. A cross section of this pool is in Figure 4. Legal description: SW¼ SW¼ SW¼ Section 36, T.1N., R.19W.

18. Pool 18. This is a roadside ditch along a dirt road about 0.5 miles west of Tipton, Tillman County. It is on the west side of a dirt road and lies north to south and perpendicular to Highway 5. It is over 101 m long, 5 m wide and up to 47 cm deep. It is on the opposite side of the dirt road from Pool 17. A cross section of this pool is in Figure 4. Legal description: SE¼ SE¼ SE¼ Section 35, T.1N., R.19W.

19. Pool 19 (Swimming Pool Pool). This is a roadside depression on the west side of the Tipton City Park at the intersection of Highway 5 and Highway 5C, Tillman County. It varies in size and is filled from rain or when the nearby city swimming pool is pumped onto the park. Legal description: NE¼ NE¼ NE¼ Section 1, T.1S., R.18W.

20. Pool 20 (Burrows Pool). This is a roadside ditch on the east side of the Tipton City Park at the intersection of Highway 5 and Highway 5C, Tillman County. This size of this pool is quite variable and depends on how well the drainage pipe connected to it is working. It lies north to south and is over 120 m long and 6 m wide. Legal description: NE¼ NE¼ NE¼ Section 1, T.1S., R.18W.

21. Pool 21 (Mexican Pool). This is a roadside depression about 30 m south of Pool 19 on the east side of a dirt road inside the city limits of Tipton, Tillman County. It filled only twice during this study. Legal description: NE¼ NE¼ NE¼ Section 1, T.1S., R.18W.

22. Pool 22. This is a roadside ditch on the north side of Highway 5C, 4.4 miles east of Tipton, Tillman County. It runs north and south on the east side of a dirt road and is perpendicular to Highway 5C. It is over 150 m long and 2 m wide. Its depth can be over 70 cm. A cross section of this pool is in Figure 4. Legal description: SW¼ SW¼ SW¼ Section 36, R.1N., R.18W.

23. Across Road 22 Pool. This is a roadside ditch on the north side of Highway 5C about 4.4 miles east of Tipton, Tillman County. It runs north and south on the west side of a dirt road and is perpendicular to Highway 5C. It is 50 m long, 2.8 m wide and lies on the opposite side of the dirt road from Pool 22. Legal description: SE¼ SE¼ SE¼ Section 35, T.1N., R.18N.

24. Tadpole Shrimp Pool. This pool lies about 2 m east of Pool 22 and is parallel to it. This pool usually fills once each year and contains a large population of tadpole shrimp (*Apus longicaudatus*). Legal description: SW¼ SW¼ SW¼ Section 36, T.1N., R.18W.

25. Swam Ranch Pool #1. This pool lies along the edge of and into a cultivated field. It covered over an acre when filled and was permanently destroyed in 1971. It was located 1.37 miles west of Tipton, Tillman County. Legal description: SW¼ SE¼ SW¼ Section 35, T.1N., R.19W.

26. Swan Ranch Pool #2. This pool occupied part of a field when filled, but drainage usually prevented its formation. It is located 1.35

miles west of Tipton, Tillman County, on the north side of Highway 5. Legal description: SE¼ SW¼ SW¼ Section 35, T.1N., R.19W.

27. Headgate Pool. This was one of the smallest pools and was only 1.1 m wide and 1.7 m long. It formed between two cement slabs used previously for irrigation. It is located 1.12 miles west of Tipton, Tillman County. Legal description: SW¼ SE¼ SW¼ Section 35, T.1N., R.19W.

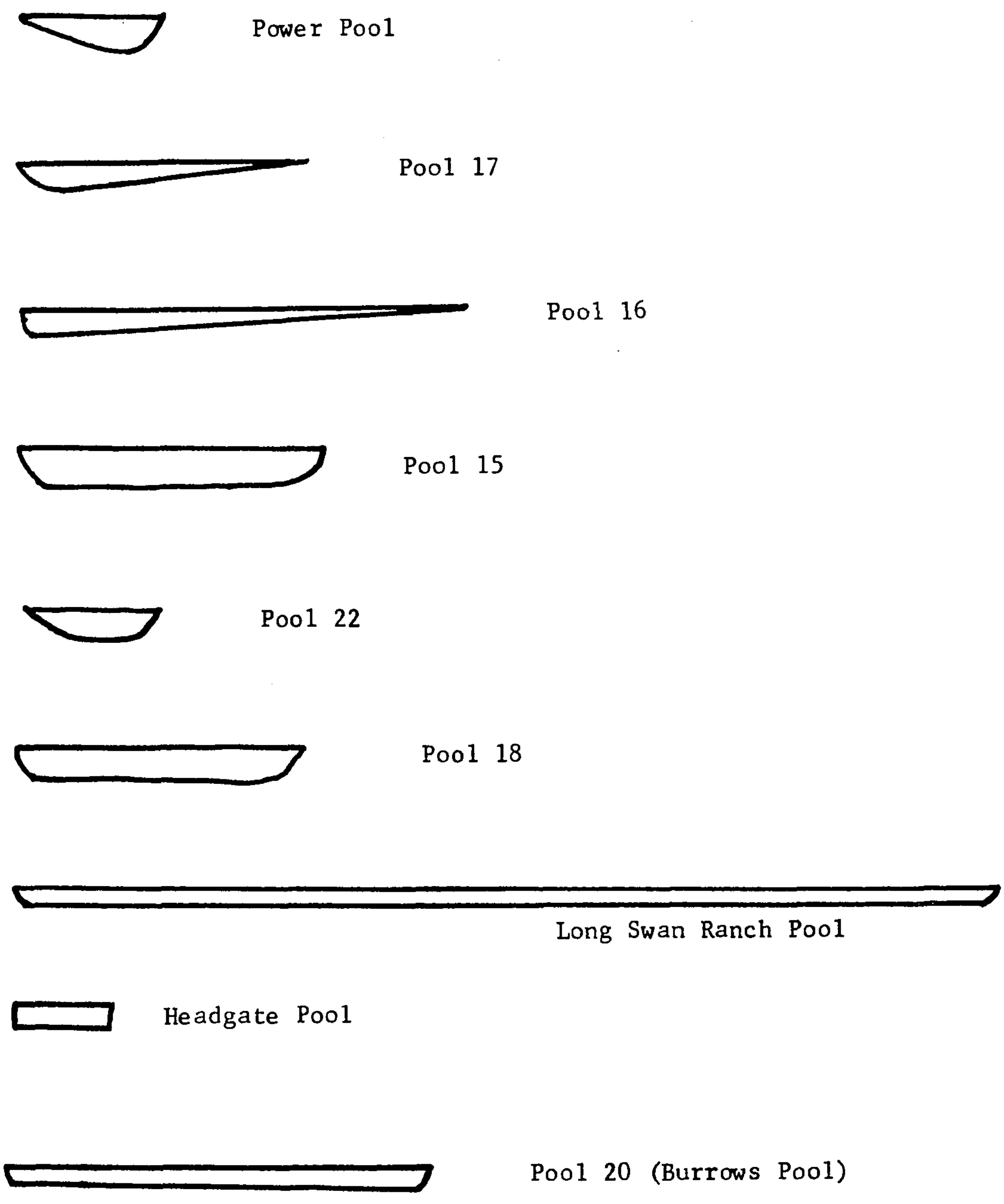
28. Long Swan Ranch Pool. This long shallow pool usually formed in the late summer or early fall and its basin was a shallow roadside ditch on the north side of Highway 5. It is located about 1.1 miles west of Tipton, Tillman County. Legal description: SE¼ SW¼ Section 35, T.1N., R.19W.

29. Big Pearl Pool. This pool was first examined in 1970 and is located 1.8 miles west of Indiahoma on the north side of Highway 62, Comanche County. It was dry most of 1970 and all of 1971. Legal description: SE¼ SW¼ Section 21, T.2N., R.3W.

30. Buffalo Pool. This small pool is located 0.2 miles west of the Rush Lake Turnoff, Wichita Mountains Wildlife Refuge, Comanche County. It was first examined in 1970 and contained water for only a short time. Legal description: NE¼ SW¼ Section 17, T.3N., R.3W.

31. Donut Pool. This pool is located on the east side of Flood Street inside the city limits of Norman, Cleveland County. It was periodically tested during 1970 and 1971, and was frequently disturbed by people. Legal description: NE¼ SE¼ NW¼ Section 30, T.9N., R.2W.

Figure 4. Cross sections of selected pool basins in southwestern Oklahoma. Scale 5 mm = 50 cm.



CHAPTER IV

PHYSICO-CHEMICAL ASPECTS

Introduction

Chemical features of temporary pools received attention since various authors have reported that spadefoots use temporary pools and only certain temporary pools. Two approaches were taken. Chemistry of the soil was determined to establish the reserve values of the pool basins and surrounding area and the chemistry of the water was determined to establish the actual chemical conditions in the environment of the spadefoot.

Methods

Two series of soil samples were collected from dry pool basins and the surrounding areas during 1969 and 1970. All soil analyses were carried out by John Baker, Extension Soil Specialist, Oklahoma State University, Stillwater. The results of these analyses and the procedures followed for chemical determinations are listed in Appendix III.

Water temperatures were measured with a Whitney Underwater Thermometer (Model TC-5). Total dissolved solids were measured using a Myron L DS Meter (Model 532t 1). This meter measures conductivity but reads directly in ppm total dissolved solids. All other measurements were made using reagents and procedures furnished by the Hach Chemical Company, Ames, Iowa, in their Model DR-EL water test kit and based on <u>Standard Methods for the Examination of Water and Wastewater</u> published jointly by the American Public Health Association, the American Water Works Association, and the Water Pollution Control Federation. Methods used for all chemical determinations are listed in Appendix I.

Results

Soils

Soil samples are reported in Appendix III and in Table 3 for soils in pool basins and areas for several parameters. Total dissolved solids (TDS) reflect in general the relative concentrations of the other determinations and an examination of the data reveals that the values in the pool basins are usually considerably higher than values of soils surrounding the pools, and that there is considerable variation in basin samples from one pool to the next and from one year to the next.

This indicates a highly variable environment.

Iron shows considerable variation, particularly towards the high side. pH of certain pools was much lower that other pools and fluctuations ranged from 4.3 to 7.4 pool to pool but were fairly consistent in samples from basins to areas.

Water

Data in Tables 4 and 5 for the various parameters selected from detailed data presented in Appendices I and II, show the highest degree of variability in a pool at one sampling period and high variability at one sampling station within 24 hours and again the high variability in the pool during two years of study in a single pool. This variability existed in pools in both central and southwestern Oklahoma.

Table 3. Chemical features of soil from Pool 1 and Pool 2, Cleveland County, Oklahoma, and Pool 3, Pottawatomie County, Oklahoma

	Pool 1			Pool 3			Pool 2	
	Area	Basin	Basin	Area	Basin	Basin	Area	Basin
Collection Date	XII/69	XII/69	VII/70	XII/69	XII/69	VII/70	VII/70	VII/70
pH	7.1	7.4	7.2	5.8	4.3	4.9		6.4
Nitrate Nitrogen (ppm)	5.0	8.0	12.0	5.0	5.0	12.0		5.0
Phosphorus (ppm)	4.0	10.0	3.0	3.0	4.0	9.0		3.0
Iron (ppm)	20.0	60.0	38.0	52.0	140.0	225.0	Sample lost	94.0
Hardness (ppm)	80.0	285.0	195.0	40.0	50.0	40.0		85.0
% $CaCO_3$	1.3	2.9	0.3	0.7	2.0	0.0		0.0
Total Dissolved Solids (ppm)	700.0	1400.0	200.0	1400.0	1900.0	550.0		450.0

Table 4. Variations in physico-chemical data within the pool at one time, during a 24 hour study, and during the entire study for Cleveland and Pottawatomie Counties.

Property	Time: Within the pool at one time	Time: During 24 hours at one station	Time: During the entire study at all stations
Temperature (°C)	18.25 - 30.10	10.1 - 30.1	-0.5 - 39.4
Total Dissolved Solids (ppm)	70 - 160	75 - 132	15 - 425
Total Alkalinity (ppm $CaCO_3$)	14 - 30	45 - 80	10 - 330
Ca Hardness (ppm $CaCO_3$)	15 - 22	20 - 40	15 - 120
pH	5.1 - 6.3	5.88 - 7.05	4.95 - 9.25
Oxygen (ppm)	2.0 - 7.5	1.0 - 10.0	0.0 - 15.0
Turbidity (Jackson Turbidity Units)	170 - 500+	162 - 290	2 - 500+
Percentage Light Transmittance (%)	00.0 - 65.5	40.05 - 61.0	0.0 - 99.8
Iron (ppm)	0.18 - 2.0	0.30 - 3.5	0.0 - 3.5
Chloride (ppm)	4.0 - 6.5	5.0 - 20.0	4.0 - 50.0
Nitrate Nitrogen (ppm)	3.7 - 5.0	1.0 - 5.0	0.0 - 9.5

Table 5. Variations in physico-chemical data within the pool at one time, during a 24 hour study, and during the entire study in southwestern Oklahoma.

Property	Time: Within the pool at one time	During 24 hours at one station	During the entire study at all stations
Temperature (°C)	21.25 - 31.35	-0.5 - 21.02	-0.5 - 37.20
Total Dissolved Solids (ppm)	380 - 460	28.5 - 34.5	11.7 - 925.0
Total Alkalinity (ppm $CaCO_3$)	22 - 75	173 - 215	9 - 320
Ca Hardness (ppm $CaCO_3$)	5 - 55		2 - 195
pH	6.7 - 7.6	7.37 - 8.50	6.1 - 10.0
Oxygen (ppm)	7.0 - 7.0	0.0 - 8.0	0.0 - 17.0
Turbidity (Jackson Turbidity Units)	52 - 500+	110 - 155	0 - 500+
Percentage Light Transmittance (%)	14.5 - 87.0	63.0 - 73.2	0 0 - 100.0
Iron (ppm)	0.04 - 0.05	0.48 - 1.52	0.0 - 2.15
Chloride (ppm)	8.5 - 10.5		5.0 - 165.0
Nitrate Nitrogen (ppm)	2.5 - 2.7		0.0 - 20.0

Relationship of soils to water

Certain soil and water chemistry data (Pools 1, 3, 12 and 17) collected during December, 1969, and July, 1970, were examined to determine the relationship of the soil to the water and relatively close correlation was found (Table 6). Pools having either low pH or low iron in their basin soils, also had low pH and low amounts of iron in their water. Higher iron contents in either soil or water were associated with soils or waters that were acidic.

Table 6. Relationship of chemistry of the basin soil to the chemistry of the water in selected temporary pools.

	Pool 1			Pool 3		
	Basin Soil	Water		Basin Soil	Water	
Collection date	XII/69	23/XII/69	24/XII/69	XII/69	23/XII/69	24/XII/69
pH	7.4	8.27	8.05	4.3	6.44	6.37
Iron (ppm)	60	0.25	0.13	140	1.85	0.51
Hardness (ppm)	285	75	75	50	25	15
Total Dissolved Solids (ppm)	1400	105	109	1900	47.3	45.5

	Pool 12			Pool 17	
	Basin Soil	Water		Basin Soil	Water
Collection date	VII/70	9/VI/70	11/VIII/70	VII/70	2/VII/70
pH	7.0	8.57	7.86	7.4	8.24
Iron (ppm)	14.0	0.10	0.05	8.0	0.06
Hardness (ppm)	120	108	110	105	200
Total Dissolved Solids (ppm)	700	165	127	450	800

CHAPTER V

ANIMALS AND PLANTS IN THE ENVIRONMENTS

Introduction

Animals and plants were studied from the standpoint of what kinds were associated with the temporary pool environment and how these might be associated with the ecology and behavior of Scaphiopus, namely as competitors, predators, food sources, for egg site deposition, and their effect on chemical environments; particularly plants in respect to their organic accumulation on the bottom.

Methods

During this study dip net and plankton samples were collected periodically in every pool and examined for invertebrates. Invertebrates were identified by the use of Pennak (1953), Usinger (1968), Dillon and Dillon (1961), Bick and Bick (1957), Schaefer (1969) and Schaefer and Drew (1968, 1969). Some specimens were sent to various authorities for identification. A checklist of invertebrates is in Appendix IV.

A checklist of the amphibians and reptiles associated with temporary pools is in Appendix V. All adult reptiles and amphibians were identified by the use of Conant (1958), Webb (1970), and Bragg et. al. (1950c). Larval amphibians were identified by the use of Bragg (1950c) and Altig (1970).

Plants in flower were collected throughout this study and identified by the use of Goodman (1958) and Waterfall (1969). Representatives of all species have been deposited in Bebb Herbarium, University of Oklahoma, and a complete list of vascular plants identified from temporary pool environments is given in Appendix VI.

Any plants that survived filling and drying of the temporary pools and occupied the pool basin, were considered in this study. Most plants would be considered as terrestrial plants which can tolerate different water levels during the short time these temporary pools are in existence.

Results

From examination of the checklists in appendices 4, 5 and 6, invertebrates representing 7 phyla were present and reptiles and amphibians representing 7 families and plants representing 52 families were identified.

Invertebrates were largely arthropods and ranged in size from microscopic to the hydrophilid beetles. The zooplankton served as potential food for Scaphiopus larvae while hydrophilid beetle larvae served as predators.

Hydrophilid beetles were common in all temporary pools. Tropisternus lateralis was collected during every month and the larger Hydrophilus triangularis was usually the first beetle to arrive in a temporary pool after it formed. Mating pairs of H. triangularis were observed during rain as the pools formed and their egg capsules were usually built during this time. Larvae hatched within 3 days and were observed to eat Scaphiopus larvae when two days old.

Other possible predators such as garter snakes, shorebirds, mammals, fish, and turtles, were noticed on few occasions. Yellow Mud Turtles (Kinosternon flavescens flavescens) were noticed twice and then capturing and eating Rana pipiens larvae and inhabiting temporary pools after the spadefoot larvae had metamorphosed, crawled out, and dug in. A garter snake (Thamnophis sauritus proximus) was observed on one occasion, and then feeding on newly metamorphosed Pseudacris triseriata triseriata. Garter snakes were never observed around temporary pools containing Scaphiopus larvae, only after the pool had existed for some time and after Scaphiopus larvae had metamorphosed.

Boat-tailed Grackles (Cassidix mexicanus) ate S. bombifrons larvae in Tillman County (Black, 1970b) only after the pool had dried and stranded the larvae on the wet mud. Shorebirds were observed only rarely around the temporary pools in the spring when Scaphiopus larvae were present.

The only evidence of mammals was tracks of skunks around the pools. All other possible predators such as fish, were never seen.

Certain amphibians utilize the same habitat (Pseudacris streckeri, Rana pipiens, Bufo americanus charlesmithi, Hyla versicolor, Pseudacris triseriata triseriata, Gastrophryne olivacea olivacea, Bufo compactilus speciosus) but either because of size desparity and/or temporal isolation, were not considered serious predators.

A checklist of vascular plants is given in Appendix VI. Plants growing in the pool basins are very important when the pools fill with water. It is upon the standing vegetation that amphibians and many invertebrates attach their eggs and later the larvae of both invertebrates and amphibians feed upon the vegetation or the Aufwuchs attached to it. Plants also served an important role in the eutrophication process.

CHAPTER VI

REPRODUCTIVE BIOLOGY OF ADULTS OF *SCAPHIOPUS*

Introduction

Much information on the breeding of adult *Scaphiopus bombifrons*, *Scaphiopus couchi*, and *Scaphiopus holbrooki hurteri*, can be found in the literature. All are called xeric breeders by Bragg (1961b, and 1965b), dependent upon rainfall forming temporary pools for their breeding sites.

S. bombifrons and *S. couchi* utilize the same pools in Tillman County while *S. h. hurteri* is the only spadefoot utilizing temporary pools in the oak-hickory savanna of Cleveland and Pottawatomie Counties.

Methods

From the literature, personal observations, and through personal communications, records are available of 103 breeding choruses of *Scaphiopus* in Oklahoma. Adequate data is not available for *S. couchi*, even though it will be similar to data of *S. bombifrons* in southwestern Oklahoma. Table 7 gives these breeding records arranged by species.

Results

A number of significant factors on breeding were revealed by the data in Table 7.

Table 7. Breeding records of *Scaphiopus holbrooki hurteri* in Oklahoma

Locality of Breeding Site	Date of Breeding Chorus	Inches of Rainfall	Max. Air Temp. °F	Min. Air Temp. °F	Source
Cleveland Co.	14 April 1945	6.07	78	59	Bragg, 1945a
	15 April 1945	3.37	76	55	
	12 May 1945	1.43	76	58	
	12 May 1947	1.56	78	60	Bragg, 1948a
	16 May 1947	0.17	78	62	
	17 May 1947	2.58	72	60	
	9 April 1949	0.08	78	57	Bragg, 1950b
	10 April 1949	1.20	74	49	
	17 May 1949	0.04	78	58	
	18 May 1949	7.95	82	56	
	28 April 1954	1.15	85	60	Bragg, 1957b
	30 April 1954	2.65	79	51	
	1 May 1954	0.03	70	51	
	2 May 1954	0.45	70	43	
	10 May 1955	1.26	84	60	Bragg, 1956c
	11 May 1955	1.02	74	61	
	3 April 1957	3.26	70	45	Bragg, 1959b
	12 April 1957	0.26	62	27	
	20 April 1957	0.56	77	61	
	21 April 1957	1.26	71	55	
	23 April 1957	1.91	75	55	
	13 April 1960	1.25	70	62	Bragg, 1961a

Table 7. Breeding records of <u>Scaphiopus holbrooki hurteri</u> in Oklahoma

Locality of Breeding Site	Date of Breeding Chorus	Inches of Rainfall	Max. Air Temp. °F	Min. Air Temp. °F	Source
Cleveland Co. cont.	26 April 1962	2.00	84	61	Bragg, 1964b
	18 April 1968	1.70	76	56	Black, unpubl.
	7 May 1969	2.72	75	56	
	29 May 1970	2.21	86	60	
	30 May 1970	1.81	86	63	
	17 April 1970	1.43	69	55	
	27 May 1971	0.81	88	59	
	27 April 1972	1.24	63	52	
Bryan Co.	6 April 1953	2.39	66	48	Bonn & McCauley, 1953
Marshal Co.	30 April 1954	1.00	78	59	Carpenter, 1954

Breeding records of <u>Scaphiopus bombifrons</u> in Oklahoma

Locality of Breeding Site	Date of Breeding Chorus	Inches of Rainfall	Max. Air Temp. °F	Min. Air Temp. °F	Source
Cleveland Co.	4 April 1934	1.55	76	55	Trowbridge & Trowbridge, 1937
	3 May 1934	2.00	70	57	
	28 April 1935	1.20	76	51	
	8 May 1936	2.59	77	60	
	17 June 1937	.50	88	68	Bragg & Smith, 1942

Table 7. Breeding records of *Scaphiopus bombifrons* in Oklahoma

Locality of Breeding Site	Date of Breeding Chorus	Inches of Rainfall	Max. Air Temp. °F	Min. Air Temp. °F	Source
Cleveland Co. cont.	8 May 1936	2.59	77	60	Moore, 1937
	21 April 1938	0.70	81	49	Trowbridge, 1939
	22 April 1938	0.95	64	49	
	19 May 1938	0.80	77	50	
	26 March 1938	2.40	76	40	Bragg & Smith, 1942
	27 March 1938	1.00	58	42	
	28 March 1938	2.30	58	47	
	12 May 1939	1.65	65	48	
	28 June 1939	3.24	90	66	
	21 May 1940	1.60	83	63	
	22 May 1940	0.18	84	55	
	12 June 1940	0.23	75	55	
	13 June 1940	0.05	75	55	
	2 July 1940	2.37	89	69	
	3 July 1940	1.52	86	65	
	5 September 1940	1.31	84	68	Bragg, 1944a
Beckham Co.	4 May 1959	0.91	84	57	Bragg & King, 1960
	5 May 1959	1.22	71	59	
	22 May 1959	1.04	73	59	
	26 May 1959	3.21	81	56	
	4 June 1959	0.96	83	63	
Cimmaron Co.	8 May 1936	2.12	78	62	Moore, 1937
	22 May 1936	0.87	86	68	

Table 7. Breeding records of *Scaphiopus bombifrons* in Oklahoma

Locality of Breeding Site	Date of Breeding Chorus	Inches of Rainfall	Max. Air Temp. °F	Min. Air Temp. °F	Source
Pottawatomie Co.	12 May 1945	1.43	76	58	Bragg, 1945b
	14 April 1945	6.07	78	59	
Marshal Co.	30 April 1954	1.00	78	59	Carpenter, 1954
Tillman Co.	2 May 1956	3.07	77	55	Bragg, 1956b
	4 May 1961	0.73	84	61	Bragg, 1962c
	5 May 1961	0.00	91	67	
	3 June 1961	0.48	92	62	
	4 June 1961	0.48	77	61	
	5 June 1961	0.46	87	63	
	21 May 1962	1.09	92	58	Bragg, 1966
	13 June 1965	0.48	92	63	Black, unpubl.
	15 June 1965	0.00	83	63	
	16 June 1965	0.92	84	64	
	15 August 1965	1.37	77	64	
	16 August 1965	1.28	93	69	
	19 September 1965	2.76	78	62	
	20 September 1965	0.81	85	66	
	22 August 1966	0.85	74	65	
	23 August 1966	0.18	71	58	
	24 August 1966	2.38	66	54	

Table 7. Breeding records of *Scaphiopus bombifrons* in Oklahoma

Locality of Breeding Site	Date of Breeding Chorus	Inches of Rainfall	Max. Air Temp. °F	Min. Air Temp. °F	Source
Tillman Co.	22 April 1968	0.68	78	55	Black, unpubl.
cont.	10 May 1968	2.10	70	54	
	21 May 1968	0.90	72	47	
	22 May 1968	1.02	94	58	
	7 May 1969	2.20	74	55	
	14 June 1969	1.32	75	61	
	22 August 1969	2.76	86	68	
	1 June 1970	0.67	82	61	
	10 August 1970	0.28	104	70	
	11 August 1970	0.22	94	67	
	Breeding records of *Scaphiopus couchi* in Oklahoma				
Comanche Co.	7 August 1939	1.66			Bragg, 1941
	1 May 1949	2.00			Bragg, 1950b
Tillman Co.	7 May 1969	2.20	74	55	Black, unpubl.

1. Bragg (1965b), Black (1970a) and other herpetologists generally agree that breeding is associated with, or initiated by, heavy rain. The average rain for 57 choruses of S. bombifrons was 1.393 $\pm$ 1.059 inches, ranging from a low of 0.05 to a maximum of 6.07 inches. The average rain for 31 choruses of S. h. hurteri was 1.832 $\pm$ 1.669 inches, ranging from a low of 0.03 to a maximum of 6.07 inches.

2. Relatively warm air and water are necessary for breeding since low temperatures are known to inhibit it (Zweifel, 1968). Temperatures are in Fahrenheit throughout this section. Bragg and Smith (1942) set the air temperature below which S. bombifrons do not ordinarily breed as close as 11 C. Bragg (1945a) stated that breeding by S. bombifrons usually occurs above 52 F, although males may call at about 45 F. Bragg (1965b) also stated that in S. bombifrons, breeding does not occur below about 52 F (9-10 C) air temperature.

Of the 59 minimum-maximum temperatures records reported on choruses of S. bombifrons, the mean minimum was 59.05 $\pm$ 6.834 F, the mean-maximum was 79.932 $\pm$ 8.986 F. Of the 31 minimum-maximum temperature records of S. h. hurteri, the mean-minimum was 55.451 $\pm$ 7.338 F, the mean-maximum was 76.032 $\pm$ 6.600 F.

3. There has always been the question among students of the genus Scaphiopus as to why spadefoot toads use temporary water and then only certain temporary pools, and how spadefoots can determine if a pool is temporary. Bragg (1964b) hypothesized that spadefoots ready to breed must receive sensory cues either from (a) temporary water which attracts them or (b) from permanent water which repels them, and that (c) these cues are

more likely chemical than physical in nature; and that (d) permanent water often smells different to humans than does temporary water; that (e) it is likely that it also does to spadefoots. Bragg (1964b, 1969) used Pool 3 (his Pool P_1) as an example to illustrate his hypothesis.

During my research, special attention was given to the physico-chemical features of pools used and not used by adult spadefoots for breeding. Table 8 for Tillman County lists all pools that filled with rain on the night of 5 May 1969, and used or not used for breeding by S. bombifrons and S. couchi. Table 9 lists similar information for S. h. hurteri in Cleveland and Pottawatomie Counties. There was no apparent difference in those temporary pools used and not used, at least within those parameters measured. My observations lend support to a hypothesis that behavioral mechanisms are more important than the chemistry of the water in determining what temporary pools are utilized for breeding. Little in the way of permanent small pond limnology has been done in Oklahoma, thus no comparisons can be made between the physico-chemical features of temporary pools and small permanent ponds.

Spadefoot toads in Oklahoma breed almost exclusively in temporary water, such as collects in roadside ditches, low fields, shallow farm ponds, and hillside terraces. From all references mentioning the type of breeding site, only once have any species in Oklahoma used a permanent body of water for breeding. This single example was one observed by me after heavy rains in Tillman County. The Tipton City Swimming Pool contained several pairs of S. couchi and S. bombifrons in amplexus and numerous males calling on the night of 11 August 1970. Numerous eggs were also deposited in the pool.

Table 8. Physico-chemical features of pools in southwestern Oklahoma used and not used for breeding by adult *S. bombifrons* on 5 May 1969.

	Pool Number											
	11	12	13	14	15	16	17	18	19	20	21	22
Methyl-orange Alkalinity (ppm $CaCO_3$)	60.0	52.0	40.0	37.0	62.0	45.0	32.0	33.0	88.0	40.0	50.0	27.0
pH	6.55	6.42	6.65	6.90	6.40	6.70	7.20	7.00	7.10	6.80	7.00	6.90
Oxygen (ppm)	4.0	5.0	4.5	7.0	2.0	5.5	5.0	7.5	1.0	5.0	2.5	4.0
Jackson Turbidity Units (JTU)	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+	500+
Percentage Light Transmittance (%)	19.5	3.5	0.1	5.0	8.5	21.5	0.0	0.0	3.2	3.5	4.1	6.9
Eggs deposited	no	yes	no	yes	yes	yes	yes	no	yes	yes	yes	no

Table 9. Physico-chemical features of pools in central Oklahoma used and not used for breeding by adult S. h. hurteri on 8 May 1969.

	Pool Number 1	2	3	6	7	8	9	10
Air Temperature (°C)	///	24.5	23.4	24.0	///	23.6	///	///
Water Temperature (°C)	///	23.6	24.1	18.1	///	24.4	///	///
Methyl-orange Alkalinity (ppm $CaCO_3$)	85.0	18.0	19.0	90.0	42.0	27.0	19.0	50.0
pH	7.1	6.2	6.57	6.89	6.1	7.05	6.38	6.53
Jackson Turbidity Units (JTU)	415	500+	500+	193	500+	32	45	340
Percentage Light Transmittance (%)	29.0	19.5	15.5	55.5	20.0	92.0	89.0	35.5
Iron (ppm)	0.6	///	0.53	0.82	///	0.04	0.04	0.95
Males called	no	yes	yes	yes	no	yes	no	no
Eggs deposited	no	yes	no	yes	no	yes	no	no

4. Spadefoot toads are also thought to breed only in newly formed pools and only those filled by rain. On 14 June 1969, about 1.5 inches of rain fell in the vicinity of Tipton. My research pools in town did not fill with water and no breeding activity occurred. But on 14 June, the city pumped water out of the city swimming pool and onto the city park which filled Pool 19. The stimulus of rain and the presence of a water-filled pool enabled *S. bombifrons* to breed in Pool 19 on the night of 15 June, even though it was not rain-filled.

5. Records reveal that a single population may breed several times a year in the necessary environmental conditions. For example, during the spring and summer of 1968, adults of *S. bombifrons* bred four times in the Tipton area. The first breeding congresses occurred on 22 April, the second on 9 May, the third on 21 May, and the fourth on 15 July. *S. h. hurteri* is quite different with a maximum of two breedings in a given area occurring in a single year (Table 7). The problem arises as to whether the same individuals of these different spadefoots breed several times within a year, or whether different members of populations breed at different times. The latter is probably the case, because on every occasion I have witnessed breeding by members of any population, numerous other individuals within several feet made no attempt to join the chorus. Also Bragg (1950f), observed that not all females of xeric species (*Scaphiopus*) breed at their first opportunity, but, instead, collectively "stagger" breeding through a given year.

6. It is generally accepted that Oklahoma spadefoots are exclusively nocturnal. Thus it might be expected that these species breed only at night. Bragg (1945a) mentioned that he had found no case of *S. h. hurteri*

breeding in daylight, whereas a very violent storm may overcome the tendency towards completely nocturnal habits in S. bombifrons. In Tipton, I have observed choruses of S. bombifrons and S. couchi that started in early afternoon under overcast cloudy skies and rain. These choruses usually continued throughout the night.

7. Some herpetologists have assigned a given number of months as the breeding season for spadefoots, but Bragg (1945a, 1965b) was always explicit in stating that spadefoots have no breeding season. Instead, they utilize the sudden appearance of water whenever and however it happens to come. In Oklahoma, breeding occurs in spring from members of all species. S. bombifrons breed more commonly during the summer months than do S. h. hurteri. Breeding in the fall is reduced for both species. In Oklahoma, breeding by S. bombifrons starts in March and builds up to a peak in May and June. Published breeding dates for S. h. hurteri indicate that all breeding in members of this species from March to August, with the greatest number of breeding congresses recorded in April and May. From these data, it is clear that the Plains Spadefoot, Couch's Spadefoot, and Hurter's Spadefoot do not follow a seasonal breeding pattern as found in most Anura. Rather, it would seem that breeding can occur from March to September if heavy rain and warm temperatures prevail.

CHAPTER VII

DEVELOPMENT OF SCAPHIOPUS LARVAE

Introduction

Scaphiopus holbrooki hurteri adults bred in central Oklahoma temporary pools in 1968, 1969, 1970, and 1971, with successful metamorphosis of larvae occurring only on three occasions.

During the same years in southwestern Oklahoma temporary pools, above normal temperatures caused rapid evaporation of temporary pools and successful metamorphosis of Scaphiopus bombifrons and Scaphiopus couchi larvae was rare.

These observations over a period of 4 years indicate the danger to the larval spadefoots in the temporary pool environment which necessitate special embryonic and larval adaptations for successful development.

Methods

From the literature, personal observations, and through personal communications, records are available of only 19 breeding dates and the resulting successful metamorphosis of Scaphiopus larvae. Breeding dates and dates of metamorphosis are compiled in Table 12.

Thermal units, methyl-orange alkalinity, median pH, and oxygen values were compiled from chemical data of temporary pools in Appendix I. Thermal units were computed as the difference between air temperature and the surface water temperature. If air temperature was greater than surface water temperature, the difference between the two was recorded in the negative. If the surface water temperature was greater than air temperature, the difference was recorded in the positive.

Results

From data in Tables 7, 10, 11 and 12, literature, and personal observations, a number of significant factors concerning larval development were revealed.

1. Eggs of S. couchi usually hatch within 12 hours and those of S. bombifrons within 24 hours. Eggs of S. h. hurteri frequently take two days to hatch, especially after breeding in April when temperatures are frequently cool.

2. Developmental rate and survival of larvae varied between Pools 1, 2 and 3 in central Oklahoma. Examination of thermal units, methyl-orange alkalinity, pH, and oxygen, indicate chemical differences between these three pools (Table 10 and 11).

It has long been known that the rate of development of an amphibian larva is to some extent determined by temperature. On the basis of data in Table 10, Pools 1 and 2 were the warmest pools and Pool 3 the coolest pool. Larval spadefoots would be expected to metamorphose sooner from Pools 1 and 2 than from Pool 3. Little data is available to test this hypothesis due to lack of Scaphiopus larvae in these pools during the study period. Table 12 lists some periods of larval development and the temperatures during this period. There is no apparent correlation between higher temperatures and increased rate of development in this small sample.

Table 10. Yearly means of selected physico-chemical features of temporary pools. All readings (except thermal units and pH) in ppm. Number of readings indicated in parentheses.

Thermal Units

	1969	1970	2 year mean
Pool 1	+42.61 (38)	+8.58 (18)	+25.5950 (56)
Pool 2	-39.35 (22)	-1.10 (8)	-20.2250 (30)
Pool 3	-46.13 (35)	-25.29 (28)	-35.7100 (63)

Methyl-orange Alkalinity (ppm $CaCO_3$)

	1969	1970	2 year mean
Pool 1	85.7837 (37)	96.9000 (20)	89.6842 (57)
Pool 2	36.9583 (24)	70.7619 (21)	52.7333 (45)
Pool 3	28.6000 (35)	41.1851 (27)	33.9841 (63)

Oxygen (ppm)

	1969	1970	2 year mean
Pool 1	8.6500 (28)	8.7000 (15)	8.6674 (43)
Pool 2	6.6875 (16)	7.6785 (14)	7.1500 (30)
Pool 3	6.1400 (25)	7.7058 (17)	6.7738 (42)

pH (median)

	1969	1970	2 year mean
Pool 1	7.85 (30)	7.60 (20)	8.00 (50)
Pool 2	6.74 (17)	7.28 (14)	6.91 (31)
Pool 3	6.40 (26)	6.90 (27)	6.67 (54)

Table 10 cont. Yearly means of selected physico-chemical features of temporary pools. All readings (except thermal units and pH) in ppm. Number of readings indicated in parentheses.

	Methyl-orange Alkalinity (ppm $CaCO_3$)		
	1969	1970	2 year mean
Pool 11	152.0909 (11)	71.6666 (3)	134.8571 (14)
Pool 12	158.5555 (9)	108.8333 (6)	138.6666 (15)
Pool 15	96.7142 (7)	-------	-------
Pool 16	152.5000 (6)	-------	-------
Pool 17	92.0769 (13)	86.8000 (5)	90.6111 (18)
Pool 18	43.4000 (5)	-------	-------
Pool 19	114.3333 (3)	142.4000 (5)	131.7500 (8)
Pool 20	42.6666 (3)	130.6666 (3)	86.6666 (6)
Pool 22	57.0000 (6)	20.0000 (2)	45.6666 (9)
Power Pool	38.2000 (5)	32.3333 (3)	36.0000 (8)
Swan Ranch Pool #1	67.6666 (9)	-------	63.1000 (10)

	Oxygen (ppm)		
	1969	1970	2 year mean
Pool 11	7.6666 (9)	6.0000 (1)	7.5000 (10)
Pool 12	10.0000 (5)	8.0000 (4)	9.1111 (9)
Pool 15	7.5000 (5)	------	------
Pool 16	7.5000 (4)	------	------
Pool 17	5.9545 (11)	6.2000 (5)	6.0312 (16)
Pool 18	5.2500 (2)	------	------
Pool 19	1.0000 (1)	6.3750 (4)	5.3000 (5)
Pool 20	5.0000 (1)	------	------
Pool 22	2.0000 (3)	6.0000 (1)	3.0000 (4)
Power Pool	5.0000 (1)	------	------
Swan Ranch Pool #1	7.0000 (7)	------	7.2500 (8)

Table 10 cont. Yearly means of selected physico-chemical features of temporary pools. All readings (except thermal units and pH) in ppm. Number of readings indicated in parentheses.

	pH (median)		
	1969	1970	2 year median
Pool 11	8.15 (11)	////	7.70 (14)
Pool 12	8.27 (8)	7.10 (6)	8.15 (14)
Pool 15	7.13 (7)	////	////
Pool 16	7.44 (6)	////	////
Pool 17	7.23 (12)	7.03 (5)	7.00 (17)
Pool 18	7.05 (4)	////	////
Pool 19	////	////	7.10 (8)
Pool 20	6.80 (2)	6.74 (3)	6.77 (5)
Pool 22	6.90 (4)	////	6.80 (6)
Power Pool	6.88 (4)	6.75 (3)	6.81 (7)
Swan Ranch Pool #1	7.30 (7)	////	////

Table 11. Yearly means of selected physico-chemical features of Pool 2 before and after being destroyed by highway construction. All readings (except pH) in ppm. Number of readings indicated in parentheses.

	Prior to destruction in fall, 1969.	After destruction, fall, 1969, through 1970.
Methyl-orange alkalinity (ppm $CaCO_3$)	36.8500 (20)	65.4400 (25)
Oxygen (ppm)	6.6875 (20)	7.6785 (25)
pH (median)	6.68 (20)	7.28 (17)

Table 12. Records of breeding and metamorphosis of *Scaphiopus* in Oklahoma. Temperatures in °F.

Locality of Breeding Site	Date of Breeding Chorus	Number of days to Metamorphosis	Mean Max. Air Temp.	Mean Min. Air Temp.	Source
		Scaphiopus bombifrons			
Tillman Co.	7 May 1969	17	80.6	56.1	Black, unpubl.
	7 May 1969	32	85.3	58.9	
		Scaphiopus holbrooki hurteri			
Cleveland Co.	3 April 1957	37	70.2	49.8	Bragg, 1959b
	12 April 1957	20	71.7	52.8	
	12 April 1957	19	71.5	52.8	
	21 April 1957	46	76.6	57.9	
	21 April 1957	26	75.1	56.1	
	10 April 1949	30	77.2	53.4	Bragg, 1950b
	18 May 1949	14	85.9	62.4	
	18 May 1949	16	86.7	63.6	
	12 May 1947	14	76.3	57.6	Bragg, 1948a
	17 May 1947	10	72.3	55.9	
	14 April 1945	26	72.6	49.8	Bragg, 1945b
	28 April 1954	24	74.5	51.6	Bragg, 1957b
	2 May 1954	22	74.5	51.6	
	11 May 1955	16	79.9	59.9	Bragg, 1956c
	13 April 1960	37	79.0	54.7	Bragg, 1961a
	29 May 1970	16	82.0	61.6	Black, unpubl.
	27 April 1972	15	74.7	53.0	

3. Data in Table 10 indicates a wide variation in pH, methyl-orange alkalinity, and oxygen between the central Oklahoma temporary pools and those in southwestern Oklahoma.

Pool 3 had lower pH, alkalinity and oxygen values and higher values of iron than did Pools 1 and 2. Other physico-chemical features (Appendices I, II, III) indicate that Pool 3 was usually clear and had decomposing vegetation on the bottom frequently causing the water to be reddish in color. A pH below 7, always less than 100 ppm alkalinity, oxygen frequently dropping below 1 ppm at night and comparatively high iron due to low pH increasing the solubility of iron, created an unfavorable habitat for Scaphiopus eggs and larvae and probably caused the complete loss of all eggs prior to hatching in 1968, 1969 and 1970. This hypothesis can be further examined by looking at Pool 2 (Table 11). Prior to September, 1969, Pool 2 had low pH, alkalinity and oxygen dropping below 1 ppm at night (see Appendix III for circumdiel cycles in Pool 2). During 1969, no Scaphiopus larvae survived past hatching. After Pool 2 was destroyed and reformed in the fall of 1969, pH, alkalinity and oxygen values all increased and Scaphiopus larvae survived to metamorphose in 1970 and 1972.

There appears to be a specific range of chemical features in temporary pool waters that make them suitable for successful hatching and development of S. h. hurteri larvae even though Bragg (1950f) states:

> "I thought it wise to check some of the more obvious physical and chemical features of the water for possible factors which may effect the rates of development and growth (of S. h. hurteri). These data are not presented in detail because they were consistently and unquestionably negative. Variation in temperature in pools (and diurnal-nocturnal fluctuation of temperature), in hydrogen ion

concentration (pH and methyl-orange and phenolphthalein alkalinity) and total carbonates and bicarbonates in the water obviously were not the determining factors, singly or collectively, in behavior or in growth and developmental rates of tadpoles".

4. In southwestern Oklahoma, most pool waters were chemically similar (Table 10). The basic difference between pools is one of depth and direction in which they lie (Figure 4). Most successful hatching and development occurred in shallow pools that laid in an east to west direction such as Pools 12 and 16. Deeper pools like Pool 15 and Burrows Pool usually had Scaphiopus eggs that decomposed before hatching or larvae that did not develop normally. Greater depth was also associated with greater amounts of decomposing and live vegetation, and low alkalinity, pH, and oxygen values (see Appendices I, II, and III).

Pool 22 was never used for breeding by either S. bombifrons or S. couchi, even though they were frequently collected on roads adjacent to this pool and breeding in nearby pools. Pool 22 (Table 10) has a lower pH, low alkalinity, and low oxygen values compared to other temporary pools in the same area. This pool also lies north to south and is subject to cold northern winds in the spring when spadefoots are breeding. This was also the case for Pool 20 (Burrows Pool).

Pools in southwestern Oklahoma with low pH, methyl-orange alkalinity, and oxygen values, greater depth with increased vegetation, and even though temporary in nature and filled by rain, did not offer favorable ecological habitats for Scaphiopus larval development. Some physical or chemical conditions in certain of my research pools, such as Pool 3, may have deleterious effects on the embryos, the larvae, or on the fertilization process itself of Scaphiopus.

CHAPTER VIII

TERMINOLOGY OF AGGREGATIONAL BEHAVIOR

Introduction

Studies of the behavior of amphibians have largely been absent in herpetological literature. The only larval anurans studied in any detail have been those of *Scaphiopus* in Oklahoma by A. N. Bragg, and in Virginia by N. D. Richmond (1947). R. M. Savage (1935, 1952) presented considerable information on the ecology of *Rana temporaria* larvae.

A. N. Bragg published numerous papers on the subject of aggregational behavior, but did not offer adequate explanations on the actual formation of aggregations and whether they were the result of mutual social attractions between larvae. Brattstrom (1962) and others have questioned some aspects of Bragg's work in regard to whether aggregations were actually social, as no experimental data was usually presented other than observations.

Methods

Through many workers, especially A. N. Bragg, a vocabulary has been built up to describe behavior of anuran larvae. The following results are intended to list most terms used and those species showing this type of behavior. Many of the definitions are adapted from an unpublished manuscript *The Frogs and Toads of Oklahoma With Emphasis on Their Habits* by A. N. Bragg, publications by other workers, and through personal observations and personal communications.

Results

Definitions

The terms aggregation and schooling must be defined before meaningful data can be presented on behavior of spadefoot larvae. These terms have been used indiscriminately by students of anuran larval behavior. Bragg (numerous papers) has used both aggregation and schooling in his descriptions, but defined only aggregation. Bragg defines an aggregation as "any massing of individuals regardless of the causes". He further divided aggregations into social and asocial aggregations. It is quite evident from the following glossary of terms used in describing anuran larval behavior, that such actions have not been related to the concurrently developing study of aggregational and schooling behavior of fishes.

Evelyn Shaw in Aronson (1970) in a review of definitions of schooling and aggregation used by students of fish behavior, reported that investigators at the 11th International Ethological Congress, Rennes, France, agreed that the term school should be used to designate any grouping of fish that is a result of biosocial attraction among the fish. To differentiate the way in which the fish are oriented to each other, the term polarized school signifies a group showing parallel orientation and non-polarized school is a group not showing parallel orientation. The word aggregation should not be used when referring to fish that are socially attracted to each other. It could still be employed to indicate that fish come together as a direct response to extrinsic conditions or when there is a reasonable doubt as to whether or not fish are socially attracted to each other.

Wassersug (in manuscript) has suggested the following categories of active aggregation in larval anurans:

1. Simple aggregates based on biotaxis other than biosocial mutual attraction. (Bragg's asocial aggregates)
    a. polarized
    b. non-polarized
2. Schools or biosocial aggregated (Bragg's social aggregates)
    a. polarized
    b. non-polarized

These categories are acceptable to me, but do not differ from those of Bragg which have already appeared in numerous publications. Thus I will continue to use Bragg's terms of asocial and social as the term biosocial is redundant with the term social being more acceptable. I will incorporate the terms of polarized and non-polarized which will help in differentiating the complexity of certain types of aggregations.

The term pod should be introduced into the herpetological literature. This term refers to groups of fish that resemble the aggregating and schooling species, except that they do not leave swimming clearance and come into contact. The mean spatial distance between fish reaches zero (Breder, 1954). This term can be applied to certain types of aggregations in *Scaphiopus*.

The following is a glossary of terms used in describing anuran larval behavior.

I. Aggregational Behavior: An aggregation is any massing of individuals regardless of the cause.

A. Feeding Aggregations: Larvae feed together in groups, mutually beneficial; seen by Bragg in *S. bombifrons*, *S. couchi*, and *S. h. hurteri*, and also reported in *S. h. holbrooki* by Richmond (1947)

1. Social Type: Larvae clump together by mutual attraction of some sort.

a. Reported by Bragg in *S. h. hurteri* and *S. bombifrons* and probable in *S. couchi* and questionably present in *S. h. holbrooki* (Richmond, 1947).

b. Reported by Bragg in *Bufo woodhousei woodhousei*, *Bufo woodhousei fowleri*, *Bufo americanus americanus*, *Bufo americanus charlesmithi* and in *Bufo boreas boreas* by Carpenter (1953) and Black (unpubl.).

2. Asocial Type: Larvae react simultaneously to a food source, the clustering incidental to this.

a. Present in all spadefoot species named above and probable in others.

B. Metamorphic Aggregations: Larvae cluster in large masses in shallow water near shore or on the bottom during early phases of metamorphosis after feeding has ceased.

a. Reported in *S. h. hurteri*, *S. couchi*, and *S. bombifrons* by Bragg, always social in nature. Very probable in *S. h. holbrooki* and possible in other species of spadefoots, but still unknown.

b. Also reported in *Bufo americanus charlesmithi* by Bragg and in *Bufo boreas boreas* by Carpenter (1953).

C. Premetamorphic Protective Aggregations: So far seen only in very warm shallow water and thought, or known in some cases, to be protection against individual water loss.

1. Premetamorphic Clumping: Known in *S. h. hurteri* only (Bragg), but since metamorphic aggregations in this species and in *S. couchi* serve also to conserve water, such grouping is to be expected in the latter.

2. Scooping Aggregations: A small proportion of tadpoles present scoop out or deepen depressions in the bottom as the water level falls dangerously low.

a. Reported by Bragg in *S. h. hurteri* and *S. bombifrons*. Probable in other species of *Scaphiopus*.

b. Also reported by Ford and Breed (1970) in Hyla arenicolor and Bufo punctatus.

D. Mixed Type Aggregations: Seen only once where many slowly feeding schools contained metamorphosing individuals that emerged from the school to the shore. The species was S. bombifrons (Bragg and King, 1960): social in character.

E. Protective Aggregations: Aggregating may be a possible protective behavior against parasites such as leeches or predators such as the water scavenger beetles.

a. Found in S. hurteri (Bragg, 1965a), S. bombifrons (Black, 1970a), and probable in Rana pretiosa (Carpenter, 1953).

F. Thermal Aggregations: Aggregation is apparently the result of individual larvae responding to micro-climatic thermal gradients.

a. Observed in S. h. hurteri, S. bombifrons, Rana pipiens, Hyla versicolor, Pseudacris nigrita triseriata (Bragg, unpubl.); Hyla regilla (Brattstrom and Warren, 1955); and Hyla crucifer, Rana boylei, Bufo boreas, Bufo canorus (Brattstrom, 1962).

G. Hatching Aggregations: Larvae after hatching remain on the jelly in groups.

a. Observed in Rana areolata areolata, Rana areolata circulosa (Bragg, 1953) and Bufo americanus charlesmithi and Rana pipiens (Black, unpubl.).

H. Egg-Site Aggregations: Hatching larvae may stay aggregated at the place of oviposition and on surrounding vegetation.

a. Observed in Bufo punctatus (Tevis, 1966); Ascaphus truei (Metter, 1964), and most Bufo (Bragg, unpubl.)

I. Post-Hatching Aggregations: The hatching aggregation moves from the site of oviposition and aggregates on surrounding vegetation.

a. Present in Rana areolata areolate (Bragg, 1953) and Bufo americanus charlesmithi and Rana pipiens (Black, unpubl.).

J. Deep-Water Aggregations: Shortly after feeding begins, the aggregation migrates to the nearest deep water.

a. Observed in Bufo punctatus (Tevis, 1966).

K. Feeding Dispersal: With the maximum rate of growth, the aggregations are not maintained. The larvae are widely dispersed in search of food.

a. Observed in Bufo punctatus (Tevis, 1966).

II. Predacous Behavior: We are confronted with several closely related phenomena which Bragg (1964a) defines as follows:

1) Carnivorous = pertaining to the eating of other animals or their parts.

2) Predaceous = pertaining to catching, killing and eating (or attempting to eat) other animals.

3) Cannibalism = feeding upon one's own kind (species) dead or alive.

The following summary of predaceous activity adapted from Bragg includes:

A. Dimorphic Cannibalistic Tadpoles

1. Known only in S. bombifrons but strongly suspected in others of the subgenus Spea.

2. Unknown and improbable in the subgenus Scaphiopus.

B. Predaceous Cannibalism but no dimorphism known in:

1. S. h. hammondi (when large). Dimorphism is strongly suspected. Bragg has recently seen one preserved tadpole of S. h. intermontanus from Washington which had mouthparts suggestive of cannibalism.

2. S. h. holbrooki (Ball, 1936) : S. h. hurteri and some S. bombifrons on tadpoles with shriviling tails or on young juveniles.

3. S. couchi on newly metamorphosing larvae and other larvae regardless of physical condition (Mayhew, 1965).

C. Predation without cannibalism

1. S. bombifrons on larvae of Bufo cognatus (but not premetamorphic Bufo compactilus speciosus), larvae of S. couchi, metamorphosing Bufo compactilus speciosus and fairy shrimp (Apus longicaudatus).

2. S. h. hammondi on mosquito larvae. S. h. hurteri on mosquito larvae but not Daphnia, at least in one culture.

3. Rana catesbeiana, Rana clamitans, Bufo americanus charlesmithi and Pseudacris streckeri on dead larvae of Pseudacris streckeri and Bufo americanus charlesmithi. Rana clamitans on dead larvae of Ambystoma texanum. All these records from Black (unpubl.).

4. To be expected in other species, but still unobserved.

CHAPTER IX

DEVELOPMENT OF AGGREGATIONAL BEHAVIOR

Introduction

The development of aggregational behavior in larvae of *S. bombifrons*, *S. couchi*, and *S. h. hurteri* was observed during the springs and summers of 1969, 1970, and 1971. The development in members of each species was followed in the field and under laboratory conditions.

Vision has been found to be the primary sensory stimulus in fish to fish attractions by Shaw (1960, 1961), Atz (1953) and Breder (1959). My observations on *Bufo americanus charlesmithi* (Black, 1969) led me to hypothesize that vision was the primary sensory stimulus in larva to larva attractions and that this led to the formation of aggregations and schools in *Scaphiopus* larvae. Wassersug and Hessler (1971) reported that *Xenopus laevis* form aggregates based solely on the visual presence of other individuals, and Mares (1972) suggested that visual cues may be important in the formation and maintenance of aggregations in *Bufo marinus* larvae.

Methods

To determine whether or not visual attraction develops parallel to the appearances of schools and aggregations, the following experiment was initiated and modified from Shaw (1958, 1960).

Rearing Techniques

Approximately 20 eggs of each species being tested were placed into a nine inch finger bowl containing well water from the Animal Behavior Laboratory, University of Oklahoma. Water was changed every two days. Hatching at laboratory temperatures of 22 to 23 C occurred within 24 hours after fertilization and newly hatched larvae were not removed from the bowls. Larvae began feeding within 24 hours of hatching and the remaining egg jelly often served as food. The larvae were fed boiled lettuce and kept in uncrowded condition; no growth inhibition was noted.

Experimental Procedure

A freely swimming larva of a known age was confined to a 9 inch finger bowl filled with water. The larva was allowed to become accustomed to the bowl. A narrow glass tube of a certain diameter (determined by the size of the larva later to be put inside it) was filled with water and plugged at both ends with a cork and placed across the middle of the glass finger bowl containing the freely moving larva (Figure 5-A). The larva was free to swim over, and around each end of the tube. After the larva showed no fright from the introduction of the tube filled with water, the experiment was started. Fright was usually indicated by a frenzied movement of the larva around the bowl and no experiment was initiated until this behavior ceased. A five minute record was then taken of the number of times the freely moving larva oriented closely to the tube and moved along or over it for at least 5 seconds. This movement oriented with the tube could be swimming or feeding along it. At the end of the five minutes, the tube containing only water was replaced by an identical tube containing a larva

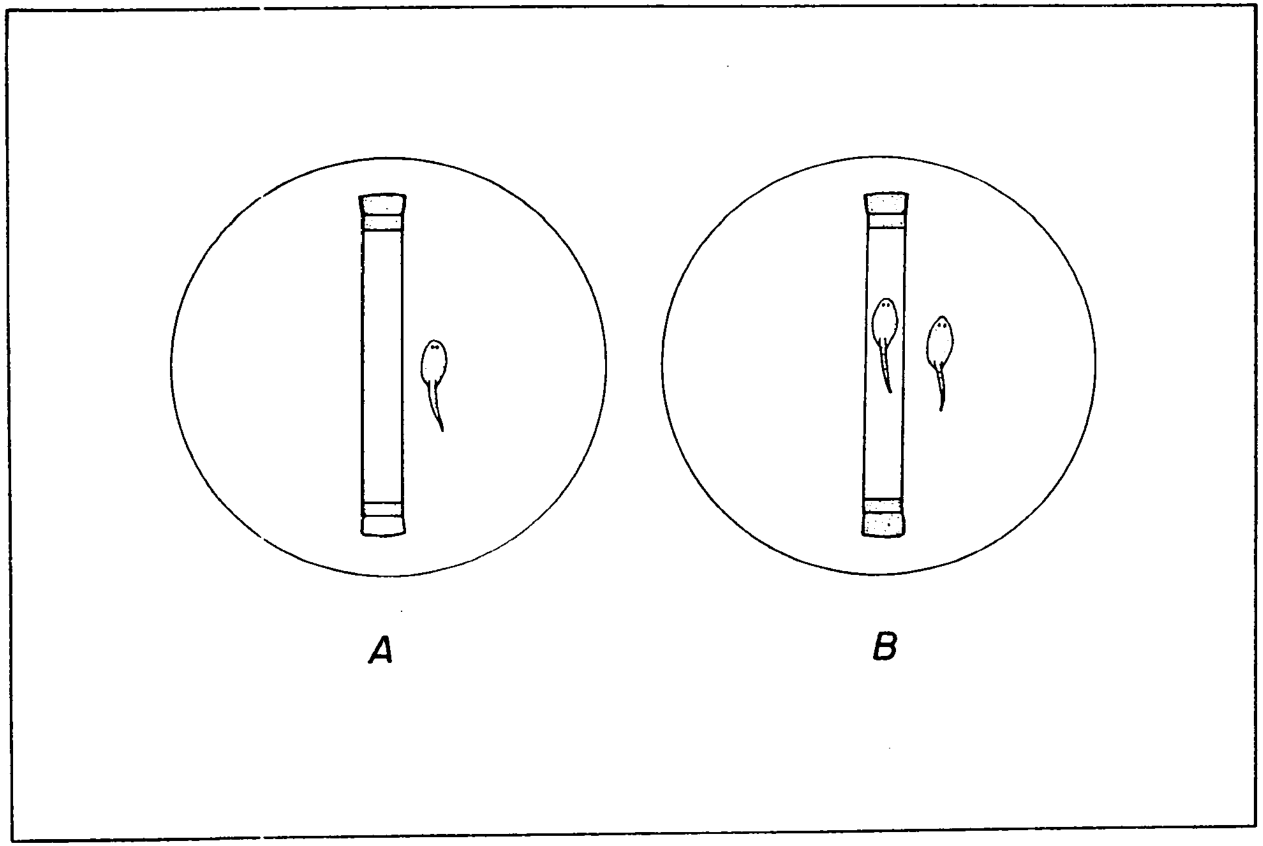


Figure 5. Experimental design for experiments on visual attraction in *Scaphiopus* larvae.

the same size as the freely swimming larva in the bowl (Figure 5-B). Another five minute observation was then taken when the freely moving larva in the finger bowl showed no sign of fright. This experiment was carried out on 10 different larvae which constituted the test group. The larva within the tube was restricted to swimming up and down the length of the tube.

Larvae of each species were tested each day for the first seven days after hatching and then every other day until the front legs erupted and metamorphosis occurred. After each testing, larvae were measured with vernier calipers from the tip of the snout to the tip of the tail.

The following information was recorded for each 5 minute test period with the tube containing only water and then the tube containing a larva. A Clebar stopwatch was used for all time recordings.

1. The total seconds each larva spent of 5 seconds or more in movement and orientation with the tube in the finger bowl for each 5 minute test period.
2. The number of orientations the tadpole made with the tube in the finger bowl which lasted for 5 seconds or more in each 5 minute test period.

Results

To determine whether or not visual attraction develops parallel to the emergence of aggregations, the experiment just described was used with larvae of three species of Scaphiopus. Tables 13 through 23 record the data gathered from testing larvae with the tube containing no larva (control tube) and the tube containing a larva. The following significant factors were revealed.

1. Until larvae of S. bombifrons were about 4 days old, there was little difference between orientations with the control tube or the tube containing a larva (Table 13). On the fourth day after hatching and until metamorphosis, there was a greater number of orientations with the tube containing a larva than the control tube, indicating a visual attraction between larvae of S. bombifrons. The number of orientations to both tubes sharply decreased the day prior to metamorphosis and all orientations ceased when the first front leg erupted.

2. In S. couchi, the number of parallel orientations was greater with the tube containing a larva than with the control tube starting from the seventh day until metamorphosis (Table 14), and the second day to metamorphosis (Tables 15 and 16). This indicated larva to larva attraction based on vision in S. couchi.

Visual attraction developed gradually, but became most evident about 7 days after hatching. Visual attraction apparently paralleled the appearance of aggregations in members of this species.

3. Until S. h. hurteri larvae are about 4 days old, there was little difference between orientations with the control tube or the tube containing a larva (Tables 17, 18 and 19). From about the seventh day to the eleventh day, there was a greater number of orientations with the tube containing a larva indicating a visual attraction between larvae of S. h. hurteri. This coincides with the formation of aggregations in the natural pools.

4. As a means of examining my experimental design for testing the development of visual attraction in Scaphiopus larvae, I also tested the

Table 13. The development of visual attraction in S. bombifrons larvae from Tipton, Tillman County. 2 July to 28 July 1970.

Age of larvae (days)	Number tested	CONTROL TUBE: Total seconds of parallel orientation	TUBE WITH LARVA: Total seconds of parallel orientation	CONTROL TUBE: No. orientations parallel to tube containing no larva for 5 seconds or more	TUBE WITH LARVA: No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	17.0	17.0	3	3
3	10	98.0	108.0	11	10
4	10	65.0	73.0	5	8
5	10	24.0	247.0	4	23
6	10	88.0	293.0	7	26
7	10	16.0	287.0	2	31
9	10	48.0	249.0	5	21
11	10	48.0	240.0	7	26
13	10	77.0	272.0	8	31
15	10	107.0	240.0	8	30
*17	10	42.0	227.0	6	26
19	10	173.0	193.0	8	21
21	10	49.0	315.0	7	30
24	10	15.0	264.0	2	28
26	10	5.0	65.0	1	9
**27	10	0.0	0.0	0	0

* hind legs present
** one front leg present

Table 14. The development of visual attraction in *S. couchi* larvae from Tipton, Tillman County. 2 July to 17 July 1970.

		CONTROL TUBE	TUBE WITH LARVA	CONTROL TUBE	TUBE WITH LARVA
Age of larvae (days)	Number tested	Total seconds of parallel orientation	Total seconds of parallel orientation	No. orientations parallel to tube containing no larva for 5 seconds or more	No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
5	10	399.0	186.0	20	14
7	10	172.0	233.0	20	20
9	10	201.0	395.0	11	19
11	10	255.0	526.0	18	41
13	10	189.0	343.0	13	29
15	10	424.0	535.0	19	36
*16	10	9.0	30.0	1	3

* one front leg present

Table 15. The development of visual attraction in S. couchi larvae from Pool 12, Tillman County. 11 August to 24 August 1970.

		CONTROL TUBE	TUBE WITH LARVA	CONTROL TUBE	TUBE WITH LARVA
Age of larvae (days)	Number tested	Total seconds of parallel orientation	Total seconds of parallel orientation	No. orientations parallel to tube containing no larva for 5 seconds or more	No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	75.0	121.0	9	17
3	10	186.0	525.0	9	36
4	10	20.0	204.0	3	20
5	10	98.0	297.0	13	24
6	10	208.0	152.0	21	16
7	10	41.0	189.0	6	19
*9	10	105.0	164.0	10	22
11	10	60.0	104.0	7	16
13	10	159.0	177.0	17	22
**14	10	0.0	8.0	0	1

* hind legs present
** one front leg present

Table 16. The development of visual attraction in *S. couchi* larvae from Pool 19, Tillman County. 11 August to 27 August 1970.

Age of larvae (days)	Number tested	CONTROL TUBE Total seconds of parallel orientation	TUBE WITH LARVA Total seconds of parallel orientation	CONTROL TUBE No. orientations parallel to tube containing no larva for 5 seconds or more	TUBE WITH LARVA No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	46.0	40.0	5	6
3	10	131.0	227.0	7	24
4	10	166.0	179.0	14	14
5	10	329.0	388.0	26	34
6	10	101.0	145.0	7	17
7	10	22.0	10.0	2	2
9	10	28.0	66.0	5	9
*10	10	65.0	196.0	7	21
12	10	397.0	284.0	31	29
14	10	635.0	312.0	26	29
16	10	113.0	172.0	12	18
**17	10	0.0	5.0	0	1

* hind legs present
** one front leg present

Table 17. The development of visual attraction in *S. h. hurteri* larvae from Pool 2, Cleveland County. 2 July to 16 July 1970.

Age of larvae (days)	Number tested	CONTROL TUBE: Total seconds of parallel orientation	TUBE WITH LARVA: Total seconds of parallel orientation	CONTROL TUBE: No. orientations parallel to tube containing no larva for 5 seconds or more	TUBE WITH LARVA: No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
3	10	145.0	96.0	10	6
5	10	195.0	342.0	16	23
6	10	197.0	307.0	22	24
7	10	234.0	326.0	15	29
*9	10	233.0	356.0	22	43
11	10	213.0	402.0	20	41
13	10	185.0	237.0	9	30
14	10	380.0	382.0	17	36
**15	10	5.0	7.0	1	1

* hind legs present
** one front leg present

Table 18. The development of visual attraction in S. h. hurteri larvae from Pool 2, Cleveland County. 28 May to 10 June 1971.

Age of larvae (days)	Number tested	CONTROL TUBE Total seconds of parallel orientation	TUBE WITH LARVA Total seconds of parallel orientation	CONTROL TUBE No. orientations parallel to tube containing no larva for 5 seconds or more	TUBE WITH LARVA No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	5.0	0.0	1	0
3	10	10.0	13.0	2	2
4	10	231.0	316.0	17	33
5	10	71.0	303.0	7	33
6	10	691.0	509.0	34	48
7	10	200.0	516.0	16	42
*9	10	44.0	225.0	6	28
11	10	245.0	704.0	21	58
13	10	33.0	61.0	4	8
**14	10	0.0	0.0	0	0

* hind legs present
** one front leg present

Table 19. The development of visual attraction in S. h. hurteri larvae from Pool 3, Pottawatomie County. 28 May to 10 June 1971.

Age of larvae (days)	Number tested	CONTROL TUBE: Total seconds of parallel orientation	TUBE WITH LARVA: Total seconds of parallel orientation	CONTROL TUBE: No. orientations parallel to tube containing no larva for 5 seconds or more	TUBE WITH LARVA: No. orientations parallel to tube containing no larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	10.0	5.0	2	1
3	10	17.0	29.0	3	5
4	10	344.0	445.0	30	46
5	10	32.0	297.0	4	26
6	10	399.0	402.0	28	41
7	10	128.0	383.0	12	37
*9	10	37.0	217.0	4	27
11	10	83.0	627.0	10	65
13	10	335.0	251.0	13	18
**14	10	0.0	0.0	0	0

* hind legs present
** one front leg present

development of visual attraction in single species of two genera not known to form aggregations - larvae of the Leopard Frog, Rana pipiens, and the Great Plains Toad, Bufo cognatus.

These experiments were run for 31 days or until metamorphosis occurred. All experimental methods were identical and under the same conditions as those used for Scaphiopus larvae. All experiments were started when larvae were one day old.

My experimental data on the development of visual attraction in R. pipiens larvae (Tables 20, 21 and 22), indicated that some visual attraction between larvae does occur, but shows no consistent pattern. There appeared to be random orientation with the tube whether it contained a larva or not.

No evidence of visual attraction between larvae of B. cognatus was observed with either the control tube or the tube containing a larva (Table 23). Larvae usually remained motionless on the bottom of the finger bowl whether a tube containing a larva was present or not.

One of the noticeable features of many aggregations of larval anurans is the constancy in orientation and some synchronization of speed and direction of movement. Many aggregations are characterized by stability through a variety of environmental conditions. Good photographs of aggregations of S. bombifrons larvae can be found in Bragg and King (1960) and these indicate the constancy in orientation.

Also aggregational behavior does not appear immediately after hatching in Scaphiopus but develops gradually over a period of several days. During this development, responses occur between larvae and eventually

Table 20. The development of visual attraction in *Rana pipiens* larvae from Pool 1, Cleveland County. 3 June to 26 June 1970.

Age of larvae (days)	Number tested	CONTROL TUBE: Total seconds of parallel orientation	TUBE WITH LARVA: Total seconds of parallel orientation	CONTROL TUBE: No. orientations parallel to tube containing no larva for 5 seconds or more	TUBE WITH LARVA: No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	0.0	0.0	0	0
3	10	0.0	0.0	0	0
4	10	0.0	0.0	0	0
5	10	0.0	23.0	0	1
6	10	5.0	0.0	1	0
7	10	0.0	0.0	0	0
9	10	0.0	0.0	0	0
11	10	12.0	17.0	2	2
13	10	0.0	0.0	0	0
15	10	0.0	0.0	0	0
17	10	5.0	0.0	1	0
21	10	7.0	8.0	1	1
24	10	0.0	0.0	0	0
27	10	0.0	0.0	0	0

Table 21. The development of visual attraction in *Rana pipiens* larvae from Pool 3, Pottawatomie County. 22 September to 23 October 1970.

		CONTROL TUBE	TUBE WITH LARVA	CONTROL TUBE	TUBE WITH LARVA
Age of larvae (days)	Number tested	Total seconds of parallel orientation	Total seconds of parallel orientation	No. orientations parallel to tube containing no larva for 5 seconds or more	No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	0.0	0.0	0	0
3	10	0.0	5.0	0	1
4	10	0.0	11.0	0	2
5	10	0.0	0.0	0	0
6	10	7.0	0.0	1	0
7	10	0.0	0.0	0	0
9	10	0.0	10.0	0	2
11	10	23.0	46.0	4	7
13	10	6.0	0.0	1	0
15	10	0.0	0.0	0	0
17	10	33.0	26.0	4	4
19	10	28.0	17.0	5	2
21	10	0.0	6.0	0	1
23	10	12.0	16.0	1	2
25	10	23.0	14.0	4	2
27	10	0.0	8.0	0	1
29	10	0.0	0.0	0	0
31	10	10.0	27.0	2	4

Table 22. The development of visual attraction in *Rana pipiens* larvae from Pool 3, Pottawatomie County. 22 September to 23 October 1970.

		CONTROL TUBE	TUBE WITH LARVA	CONTROL TUBE	TUBE WITH LARVA
Age of larvae (days)	Number tested	Total seconds of parallel orientation	Total seconds of parallel orientation	No. orientations parallel to tube containing no larva for 5 seconds or more	No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	0.0	0.0	0	0
3	10	5.0	5.0	1	1
4	10	18.0	17.0	3	2
5	10	0.0	0.0	0	0
6	10	0.0	0.0	0	0
7	10	0.0	0.0	0	0
9	10	0.0	10.0	0	2
11	10	16.0	23.0	2	3
13	10	0.0	6.0	0	1
15	10	16.0	16.0	2	2
17	10	17.0	12.0	3	2
19	10	39.0	40.0	4	6
21	10	20.0	0.0	4	0
23	10	30.0	15.0	4	3
25	10	91.0	30.0	11	5
27	10	11.0	41.0	2	4
29	10	5.0	22.0	1	3
31	10	31.0	42.0	5	7

Table 23. The development of visual attraction in Bufo cognatus larvae from Donut Pool, Cleveland County. 3 June to 27 June 1970.

Age of larvae (days)	Number tested	CONTROL TUBE: Total seconds of parallel orientation	TUBE WITH LARVA: Total seconds of parallel orientation	CONTROL TUBE: No. orientations parallel to tube containing no larva for 5 seconds or more	TUBE WITH LARVA: No. orientations parallel to tube containing larva for 5 seconds or more
1	10	0.0	0.0	0	0
2	10	0.0	0.0	0	0
3	10	0.0	0.0	0	0
4	10	0.0	0.0	0	0
5	10	0.0	0.0	0	0
7	10	5.0	5.0	1	1
9	10	0.0	0.0	0	0
11	10	0.0	0.0	0	0
12	10	5.0	0.0	1	0
14	10	27.0	0.0	3	0
16	10	0.0	0.0	0	0
18	10	8.0	0.0	1	0
20	10	0.0	0.0	0	0
23	10	0.0	0.0	0	0
25	10	0.0	0.0	0	0
*27	10	0.0	0.0	0	0

* one front leg present

parallel orientations between larvae develops. The development of larva to larva responses, and then parallel orientation leads to the development of aggregations, probably when the visuo-motor co-ordination becomes more highly developed in the larvae.

An important aspect of aggregational behavior is that it is an interaction between larvae and mutual responses from each larva are required to maintain an aggregation. Even though these larvae are attracted to an aggregation, they may need a certain amount of experience (learning?) before they are able to orient successfully.

Scaphiopus larvae usually form loose, non-polarized aggregations in early larval life and it is only later that the highly synchronized schools are formed. Pods, for example, form only a couple of days before metamorphosis. Perhaps it is through these early feeding aggregations that larvae become accustomed to each other and obtain this experience or learning in orientation. Later as visuo-motor co-ordination becomes more highly developed, the larvae are able to select and orient.

It is possible that this early contact with others of its own species, may well be the essential element influencing the later establishment of schooling and podding behavior, and that there may or may not be a critical time period.

CHAPTER X

FORMATION OF AGGREGATIONS

Introduction

Bragg (1965b, 1968) and Bragg and King (1960) have noted the presence of various types of aggregations in larvae of *Scaphiopus*. Bragg (1965b) summarized these aggregations and under what conditions each type of aggregation might be formed. Since larvae of *Scaphiopus* develop very rapidly, there is usually insufficient time in any one instance to observe just how aggregations are formed.

Data in the preceding chapters indicate how visual attraction develops parallel to the emergence of aggregational behavior in *S. bombifrons*, *S. couchi* and *S. h. hurteri* larvae. Even though visual attraction starts as early as the second day after hatching, social or asocial aggregations may or may not be formed until the tenth day after hatching (Bragg, 1965b) or no aggregations are formed during the larval period. Thus the question exists as to what are the actual stimuli which might cause the formation of anuran larval aggregations through larva to larva responses.

Methods

Experiments on the formation of feeding aggregations were carried out with *S. h. hurteri* larvae in twenty gallon aquaria. Approximately 100 larvae were kept in each aquarium from eggs through metamorphosis.

Experiments on other types of aggregations were carried out in aquaria and also in plastic wading pools. Other observations were conducted at natural pools when the opportunity presented itself.

Results

Feeding Aggregations

If Gerber's High Protein Cereal for Babies was sprinkled on the surface of the water, it took only a few minutes until 3 to 8 aggregations were surface feeding. These were small aggregations of 4 to 50 individuals that moved back and forth across the aquarium, mixing into each other and separating again. Many within these aggregations were not feeding for most members of any one aggregation were milling about and shoving each other. One larva reacted to the furious feeding of another larva and another to these two until a feeding aggregation formed. Even with no food in the aquarium, a finger wiggled slightly in the water caused aggregations to form. If a small piece of hamburger was dropped into the aquarium, a huge aggregation formed over and around it on the bottom. There appeared to be a larva to larva attraction with each responding to the activities of the others, not necessarily to food.

Further observations were made on the formation of feeding aggregations. Only a few segments of barley were put on the surface. A single larva found the barley and began swimming in a vertical position in fast circles. Occasionally the larva would swim with the tail beating very fast away or down and then return to the food. Other larvae soon approached this larva and all circled and bumped each other. An aggregation soon formed. This experiment has been repeated many times and usually with the same results.

On the basis of experimental observations in aquaria and also from limited observations in central Oklahoma temporary pools, a hypothesis can be suggested for the formation of some feeding aggregations in S. h. hurteri. This appears to involve swimming movements by which the larva or larvae discovering the food offer sign stimuli which informs other larvae of the discovery of food. There is no doubt that larvae recognize the swimming activity and pattern, as they form aggregations and find the food and begin to feed. The following sequence of events usually takes place:

1. The first larva to find food makes several circles around the food in a vertical position (Fig. 6) or in a horizontal position (Fig. 7). The food may be bumped with the snout during these circles, but apparently not eaten.

2. The larva then leaves the food in wide circles, still in the vertical or horizontal position, or it may swim directly away from the food in a horizontal manner (Fig. 8).

3. When this larva approaches another larva while circling or swimming away from the food, it circles and/or bumps this larva in the vertical (Fig.9) or more horizontal position (Fig.10). This circling and bumping signal is very similar to that first given to the discovered food (Figs.6 and 7).

4. The circled and/or bumped larva will do the same to another larva and that larva to another until a small group is formed, and each larva is circling and/or bumping another larva. These small aggregations of circling and/or bumping larvae form throughout the aquarium.

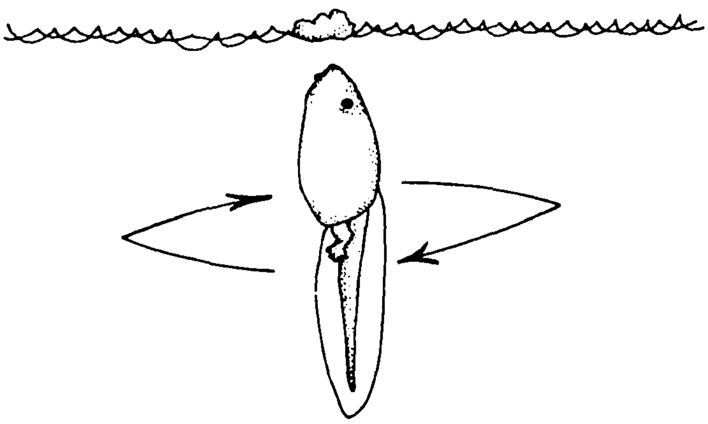


Figure 6. Lateral view of a larva circling food in a vertical position. The food may be bumped with the snout when circling.

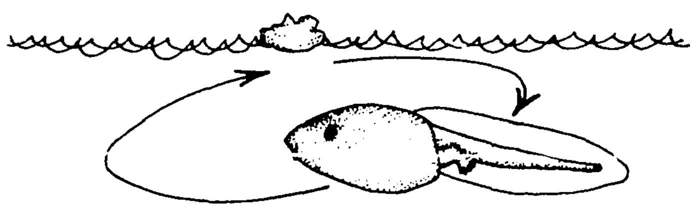


Figure 7. Lateral or side view of a larva circling food in a horizontal position. The food is usually bumped with the snout during this circling.

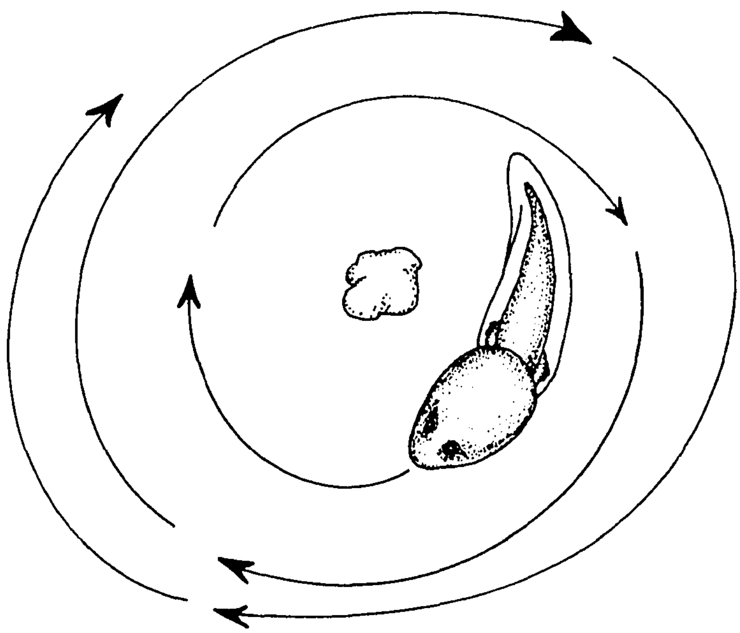


Figure 8. Looking directly down on a larva leaving the source of food in wide circles, still swimming in a horizontal position. The larva continues this ever widening circling until it comes in contact with another larva.

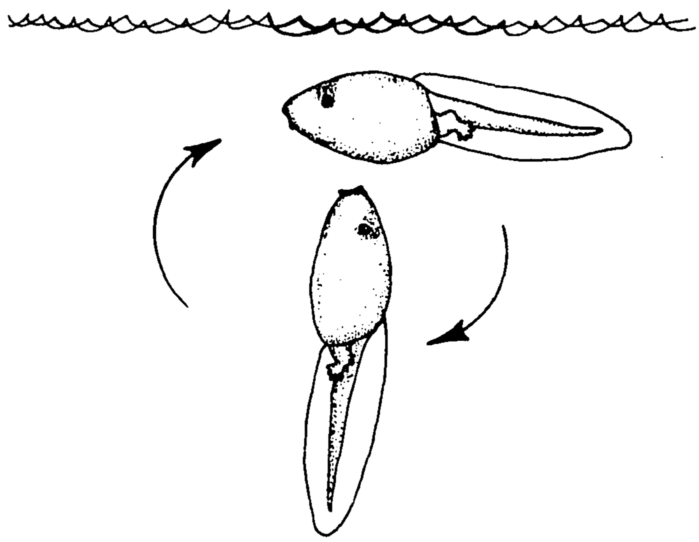


Figure 9. Lateral view of a larva circling and bumping another larva in a vertical position. This behavior signals the other larva that the circling larva has found food.

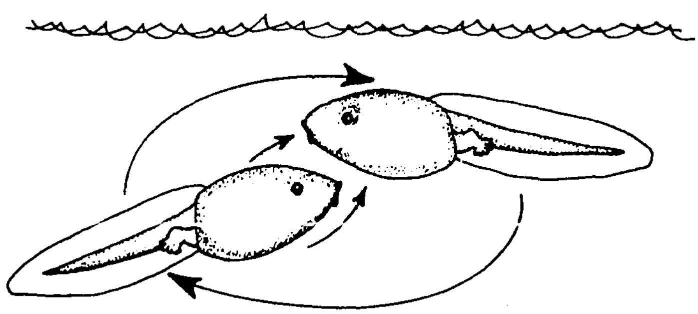


Figure 10. Lateral view of a larva circling and bumping another larva in a horizontal position. This behavior signals the other larva that the circling larva has found food.

5. Small aggregations may come together to form larger aggregations and the aggregation moves throughout the aquarium in search of food. When the food is found, the aggregation may stay to feed or if plentiful food is available, the aggregation may break apart with all larvae feeding.

6. There is no consistent leader in an aggregation, all members of the aggregation do the same thing at the same time.

Aggregations as Protective Devices

Carpenter (1953b), Bragg (1961b, 1965b) and Bragg and Bragg (1959) have discussed the possibilities of predation by anuran larvae, beetle larvae and leeches acting as a possible stimulus for the formation of aggregations in amphibian larvae. Considerable data has been presented by Bragg on how cannibalistic larvae of S. bombifrons will not enter aggregations of non-cannibalistic S. bombifrons. Aggregations may confuse predators and thus are defense against predators.

The possibility of feeding aggregations acting as protective devices for larvae of S. bombifrons against beetle larvae (Hydrous triangularis) has been reported (Black, 1970a). In this same paper I reported that when predaceously cannibalistic larvae of S. bombifrons were present in temporary pools, feeding aggregations of the non-cannibalistic larvae occurred. Cannibalistic larvae were never observed to enter feeding aggregations of S. bombifrons. During 1968 in Tillman County, cannibalistic Scaphiopus larvae and/or beetle larvae were never observed to enter aggregations, even though both moved freely outside such aggregations and throughout the pools, catching, killing and eating larvae not in the aggregations. I offered the hypothesis that the predaceously cannibalistic larvae of S. bombifrons and/or beetle larvae might act as the stimulus for the formation of protective aggregations. The stimulus presented to the larvae by the cannibalistic forms might be visual or chemical in nature. Whatever the stimulus, the response is probably the formation of an aggregation that serves as a partial protective device, as well as a cooperative effort of individuals in the aggregation to procure nutritive benefit for all.

It is probable that feeding aggregations act as protective devices against predation. The question arises as to whether these aggregations formed initially as a response to predaceously cannibalistic larvae and/or beetle larvae, or if they initially formed as feeding aggregations.

For several springs and summers, I have raised larvae of S. bombifrons and S. h. hurteri in outside plastic wading pools. Beetle larvae and cannibalistic S. bombifrons tadpoles have been introduced into these pools, but no aggregations have formed in response to them. The usual response to a beetle larva was fright and wild swimming throughout the artificial pool.

Aggregations in Response to Thermal Gradients

Brattstrom (1962) related that aggregational behavior in some anuran larvae appears to be thermally controlled, and form apparently as the result of individual larvae responding to microclimatic thermal gradients rather than aggregations being "social".

I agree that some aggregations in larval anurans are thermally controlled, but Brattstrom's observations on Hyla, Rana, and Bufo in California, Colorado, and New York may not relate to the behavior of

Scaphiopus in Oklahoma. Brattstrom's observations at a single time on one single day or even two days are not adequate to determine aggregational information. There is evidence to suggest that larvae aggregate at certain times in response to thermal gradients, but *Scaphiopus* larvae also socially aggregate.

During this research I have observed many instances of aggregations forming in response to thermal gradients and several examples from *Scaphiopus*, *Rana* and *Bufo* will be given.

On 17 May 1970, larvae of *S. h. hurteri* were found aggregated in the corner of an artificial pool at 30.7 C while temperatures in other parts of the pool were 31.0 C or higher. On 18 May 1970, these larvae were observed to move around the pool during the day. They aggregated at 28.1 C when other temperatures were 28.3 C, and later in the day at 31.6 C when other parts of the pool were at least 31.8 C. These congregations of larvae were definitely in response to temperature as the aggregations would disperse when the temperatures became lower in the evening or early morning hours.

Rana pipiens larvae have frequently been observed to aggregate in response to thermal gradients in my research pools, especially in the spring. In Pool 1 on 6 February 1970, the temperatures ranged from 11.2 to 20.2 C around the pool, but all larvae were aggregated in a temperature range of 12.4 to 15.0 C. On 11 February 1970, these larvae were aggregated at 4.15 C at 8:55 hr while temperatures in the pool ranged from 2.5 to 6.5 C. By 12:00 hr, the larvae were aggregated at temperatures of 12.6 to 13.6 C, while other parts of the pool were about 9.7 C. On 15 February 1970, Pool 1 was covered with ice and all larvae were very close to the bottom of the pool among grass and leaves. The bottom temperature was the warmest in the pool at 3.8 C.

Bufo americanus charlesmithi larvae were usually aggregated during the spring of 1969 in Pool 1. On 12 April, the pool was very shallow with isolated pools of water in the pool basin. Aggregations were found at 28.0 C in a small pool with other temperatures of 27.45 C. Another pool had aggregations at 28.6 C when other temperatures were 28.4 C. Another section of water had temperatures ranging from 18.5 to 19.15 C, but larvae were aggregated only at 19.15 C. In all these examples it was the *aggregations that responded to thermal gradients*. Whereas in the examples of *R. pipiens* and *S. h. hurteri* it was the *larvae that actually formed aggregations in response to thermal gradients*. There should be a definite distinction between aggregations formed in response to thermal gradients and aggregations that have already formed and then respond to thermal gradients.

Numerous other examples of aggregations responding to thermal gradients could be given, but on additional on *S. h. hurteri* in Pool 2 will suffice. On 10 June 1970, the large feeding aggregation was in the west end of the pool where temperatures were 22.4 to 22.6 C. All other parts of the pool had temperatures above 23.0 C. Observations on previous days which had been cooler, found the aggregations moving freely throughout the pool and never stationary at any one temperature.

Pre-Metamorphic Pod

A unique type of aggregation which has been described by Bragg (1965b) is the metamorphic aggregation. During the spring of 1972, larvae of *S. h. hurteri* formed metamorphic aggregations in Pools 2 and 3, which I observed in some detail. On 29 April 1972, *S. h. hurteri* bred in Pools 2 and 3. In about seven days the first feeding aggregations formed and remained formed until metamorphosis. Two days before metamorphosis when most larvae had well developed hind legs, the feeding aggregations formed two metamorphic aggregations in Pool 3.

These metamorphic aggregations were large masses of larvae that did not feed but remained in continuous motion. Larvae left this boiling mass only to come to the surface to gulp air and then immediately return to the mass. These masses moved very slowly from place to place around Pool 3 and occasionally the masses would split apart into small aggregations and then rejoin.

If the large aggregations were broken by a net, larvae scattered in all directions, but almost immediately started coming together until small aggregations formed and these in turn joined until the boiling mass of larvae resulted. Visual attraction between the larvae was responsible for the formation of the aggregations.

Bragg (1965b) associated metamorphic aggregations with iminent metamorphosis and that such aggregations lasted only a few hours until darkness and then the metamorphosed larvae crawled out on the bank. In Pool 3, the metamorphic aggregations were formed for two days before the first metamorphosed larva was found. These two metamorphic aggregations contained larvae with no hind legs, tiny hind legs, well developed hind legs, and some with the front legs barely erupted. By the late hours of the second day of the aggregation, larvae were starting to metamorphose and leave the aggregations. Many of those with four legs were immediately attacked by the others and injured larvae with four legs were floating on the surface of the pool. Also larvae of the beetle Hydrous triangularis were catching and killing those anuran larvae not in aggregations. Beetle larvae were never observed to enter the Scaphiopus aggregations. The majority of the spadefoot larvae did metamorphose and leave the pool during the night after over two days in a metamorphic aggregation.

Observations in Pool 2 of metamorphic aggregations were almost identical to those in Pool 3 except that in Pool 2 the aggregations formed for about 1½ days before metamorphosis. The larvae in these aggregations metamorphosed during the day and the banks were covered with tiny newly metamorphosed S. h. hurteri.

A net of larvae from a metamorphic aggregation in Pool 3 was put into a gallon jar of water for transportation back to the laboratory. The larvae did not cease their aggregational behavior in the jar. Close examination of the aggregation showed hundreds of larvae packed closely together with no space between them, and all facing down in the same direction and all beating their tails very rapidly. The hard fast movements of each larva was necessary to keep its station in the mass and to keep facing in the right direction. A larva would break from the mass, go to the surface for a gulp of air and then immediately swim back into the mass and orient with the others. Thus a metamorphic aggregation is a tightly packed mass of larvae all oriented in the same direction, all swimming in unison, and the larvae are so tightly packed that the movement of the aggregation is slow and random. Larvae enter and leave the aggregation in a circular pattern by going to the surface to get air and then returning to the aggregation and orienting with the other larvae.

There is some doubt as to whether these aggregations should be called metamorphic aggregations. The aggregations are not metamorphosing and many of the larvae within the aggregation will not metamorphose. Also in this type of aggregation the larvae do not leave swimming clearance and are in contact. These characteristics identify this type of aggregation as a pod. Therefore it would probably be best to refer to the metamorphic aggregations of Bragg as tadpole pods or pre-metamorphic pods.

Summary of results

In this chapter I have attempted to explain how feeding, thermal, protective, and premetamorphic pods might be formed. Other types of aggregations (Chapter IX) have also been described, but most aggregations probably form initially from larva to larva attractions.

Some possible advantages of aggregations are as follows:

1. Aggregations may confuse predators, act as defense against predators.
2. Aggregations allow the individual larva a place to hide within the group.
3. Aggregations are a more efficient way to move through the water and lessen the exertion of individual larvae.
4. Aggregations might act as protection from toxic agents in the temporary pool environment.
5. Aggregations apparently stimulate growth in anuran larvae.
6. Aggregations may cause an increased motivation to feed.
7. Aggregations are associated with decreased locomotor activity and decreased oxygen consumption in fish, and this may be the case for anuran larvae in aggregations.
8. Aggregations might allow larvae to be in contact with a growth promoting substance which speeds up their development when the pool is rapidly disappearing.

CHAPTER XI

GROWTH INHIBITION IN *SCAPHIOPUS* LARVAE

Introduction

In has been known for some time that body size and growth in poikilothermic animals such as anuran larvae can be influenced by environmental conditions. Some early work on the effect of environmental conditions on the growth rate of anuran larvae was that of Adolph (1931), Allee (1938), Allee, Finkel and Hoskins (1940), Bilski (1921), Goetsch (1924), Hodler (1958), Yung (1885) and Rugh (1934). The effect of crowding on growth in larvae was also studied by Adolph (1931), Rugh (1934), and Lynn and Edelman (1936). All reported that the degree of crowding to which an anuran larva was subjected by other individuals of its own or other species may have profound effects upon its growth processes. Many theories were given to explain this reduced growth rate.

Richards (1958, 1962) found a cell in the feces of *Rana pipiens* larvae which he associated with inhibited growth in larvae. Additional studies were then carried out with intraspecific effects of crowding, especially with *Rana pipiens* by Rose (1959, 1960), Rose and Rose (1961, 1965). West (1960) discussed the nature of the growth inhibiting material from crowded *Rana pipiens* larvae. Akin (1966) reported data suggesting that different species vary in their sensitivity to, and production of, the inhibition factor. Licht (1967) has presented the most intraspecific and interspecific data on growth inhibition in anuran larvae. His experiments with 17 species of larvae showed that the effects of the inhibiting cell were nonspecific; and that the inhibitor, which has been shown to be water-carried and involve an algal-like cell, could be transmitted from one species to another. His tests with Bufo woodhousei suggested the existence of an intraspecific growth-promoting substance and that metamorphosing larvae may release a nonspecific growth stimulating substance into the water which might alleviate the effect of inhibitory substances. Licht suggested that large larval aggregations such as reported by Mayhew (1965), Bragg (1965b) and Savage (1935, 1952), might result in stunted growth because of accumulated inhibitory substances. This is in sharp contrast to the views of Bragg (1965b) that larval aggregations promote development. It should be pointed out that no research on growth inhibition has been carried out in the natural habitats of anuran larvae.

Licht (1967) worked with S. couchi and found them inhibited by water conditioned by Rana pipiens larvae. Yet Rose and Rose (1961) who (after personal communication with C. Richards), stated that Scaphiopus larvae were inhibited by culture water from Scaphiopus donors, "but were not inhibited by Rana donors even when the donors contain large numbers of cells in their intestines".

During 1970, I undertook a series of experiments to test inhibition in S. bombifrons, S. couchi, and S. h. hurteri larvae.

Methods

Larvae were obtained from freshly fertilized eggs collected in the natural pools, or were collected at different ages in the natural pools. All larvae used in a particular trial were of the same size and age at the start of the experiment.

Finger bowls were used as containers. 150 ml of well water was maintained at all times in the finger bowls. Larvae were fed only on boiled lettuce which was readily eaten and did not decompose quickly in the water.

Growth was determined by measurement of dead body weight. At the end of each experiment, larvae were killed in 5% formalin, placed on filter paper to remove surface water, and then weighed.

Water was conditioned for crowding by maintaining a fixed number of larvae of one species in a finger bowl for two days. This "crowded" water was then used to raise four larvae of either the same or another species, depending on whether the testing was for intraspecific or interspecific effects. As a control, four larvae of the same size and species as the assay larvae were raised concurrently in fresh non-conditioned water. Both assay and control larvae always had food available, but the assay larvae in the crowded water could also use the fecal material left by the larvae which had conditioned the water. Every two days the crowded water and the fresh water were renewed. All experiments were run for 12 days or until the assay larvae died at which time the experiment was terminated.

The following series of experiments were carried out. The effect of water crowded by 12 *S. bombifrons* was tested on *S. h. hurteri*, *S. couchi*, and S. bombifrons. The effect of water crowded by 30 S. h. hurteri larvae was tested on S. bombifrons larvae.

Results

Data in Tables 22 through 27 shows the following significant factors.

1. Water crowded by 12 S. bombifrons larvae (30 days old) from Pool 4 inhibited the growth of S. bombifrons larvae (all one day old) from Pool 4 (Table 24), Donut Pool (Table 25), and Pool 2 (Table 26).

Those larvae from Pool 12, Tillman Co., were greatly affected by the crowded water whereas those from Pool 4 and Donut Pool, Cleveland Co., were not so greatly affected. Many assay larvae from Pool 12 died before the experiment was terminated.

In field observations in Tillman County, no larvae of S. bombifrons of two widely different ages ever occurred together. In central Oklahoma, I have frequently found larvae several days old and others over 30 days old in the same pools. Inhibition (intraspecific) would perhaps be more important in one habitat than in the other. In central Oklahoma, inhibition would be important against the many other anuran larvae in the longer lasting pools of water. Whereas in southwestern Oklahoma, inhibition would only be intraspecific or against S. couchi larvae. There is the possibility that the inhibiting factor of S. bombifrons from Cleveland County would have a greater effect on S. bombifrons from Tillman County, than on other S. bombifrons from Cleveland County.

2. S. bombifrons larvae (one day old) were inhibited by water conditioned by S. h. hurteri larvae (25 days old) (Table 27). According to Bragg (unpubl.) and Dr. C. C. Carpenter (pers. comm.), S. h. hurteri has invaded the prairie where it associates with S. bombifrons near Lake Texoma, Marshall County,

Table 24. The effect of water crowded by 12 large *Scaphiopus bombifrons* larvae from Pool 4, Cleveland County, on the growth of *Scaphiopus bombifrons* larvae from Pool 12, Tillman County. Experiment lasted from 2 June 1970 to 13 June 1970. Number of larvae is indicated in parentheses.

Species Tested	Sample Size	Total Weight in Grams Start	Finish
S. bombifrons	2a Control (4)	0.0417	0.7808
	2a Assay (4)	0.0417	0.1918
S. bombifrons	2b Control (4)	0.0417	0.7008
	2b Assay (4)	0.0417	0.2259
S. bombifrons	2c Control (4)	0.0417	0.5316
	2c Assay (4)	0.0417	0.1521
S. bombifrons	2d Control (4)	0.0417	0.7808
	2d Assay (4)	0.0417	0.1206
		CONTROL (16)	2.7940
		ASSAY (16)	0.6895

Table 25. The effect of water crowded by 12 large *Scaphiopus bombifrons* larvae from Pool 4, Cleveland County, on the growth of *Scaphiopus bombifrons* larvae from Donut Pool, Cleveland County. Experiment lasted from 2 June 1970 to 20 June 1970. Number of larvae is indicated in parentheses.

Species Tested	Sample Size	Total Weight in Grams Start	Finish
S. bombifrons	Control (4)		1.8590
	Assay (4)		0.4321
		CONTROL (4)	1.8590
		ASSAY (4)	0.6895

Table 26. The effect of water crowded by 12 large *Scaphiopus bombifrons* larvae from Pool 4, Cleveland County, on the growth of *Scaphiopus bombifrons* larvae from Pool 4, Cleveland County. Experiment lasted from 18 May 1970 to 30 May 1970. Number of larvae is indicated in parentheses.

		Total Weight in Grams	
Species Tested	Sample Size	Start	Finish
S. bombifrons	3Sb Control (4)	0.0417	1.4791
	3Sb Assay (4)	0.0417	0.6552
S. bombifrons	4Sb Control (4)	0.0417	1.5280
	4Sb Assay (4)	0.0417	0.9446
S. bombifrons	5Sb Control (4)	0.0417	1.8324
	5Sb Assay (4)	0.0417	0.9320
		CONTROL (12)	4.8395
		ASSAY (12)	2.5318

Table 27. The effect of water crowded by 30 *Scaphiopus hurteri* larvae from Pool 3, Pottawatomie County, on the growth of *Scaphiopus bombifrons* larvae from Pool 4, Cleveland County. Experiment lasted from 18 May 1970 to 30 May 1970. Number of larvae is in parentheses.

		Total Weight in Grams	
Species Tested	Sample Size	Start	Finish
S. bombifrons	1Sb Control (4)	0.0417	1.3758
	1Sb Assay (4)	0.0417	0.3366
S. bombifrons	2Sb Control (4)	0.0417	1.2486
	2Sb Assay (4)	0.0417	0.4369
		CONTROL (8)	2.6244
		ASSAY (8)	0.7735

Oklahoma. The possibility does exist that larvae of both species might occur in the same pools where inhibition could be a factor.

3. A single experiment was run on possible interspecific inhibition of S. bombifrons larvae (30 days old) on S. h. hurteri (10 days old).

Little inhibition was noted from the weights of the control and assay larvae (Table 28), but there were marked observable differences. Those in the conditioned water did not feed well and were very thin. The experiment was terminated after 7 days as the larvae of S. h. hurteri in the control water metamorphosed. Those in the conditioned water still had very tiny hind legs and were not near metamorphosis. Larvae of S. h. hurteri were definitely inhibited by water conditioned by larvae of S. bombifrons.

Table 28. The effect of water crowded by 12 large Scaphiopus bombifrons larvae from Pool 4, Cleveland County, Oklahoma, on the growth of Scaphiopus hurteri larvae from Pool 2, Cleveland County, Oklahoma. Number of larvae is indicated in parentheses.

Species Tested	Sample Size	Total Weight in Grams Start	Total Weight in Grams Finish
S. hurteri	1a Control (4)	0.2110	0.5978
	1a Assay (4)	0.2110	0.3886
S. hurteri	1b Control (4)	0.2110	0.5246
	1b Assay (4)	0.2110	0.3756
S. hurteri	1c Control (4)	0.2110	0.6577
	1c Assay (4)	0.2110	0.4410
		CONTROL (12)	1.7801
		ASSAY (12)	1.2052

4. S. couchi larvae (7 days old) in water conditioned by S. bombifrons larvae (30 days old) did not feed and all died within 4 days when the experiment was terminated (Table 29). No larvae in the control bowls died.

By the time S. bombifrons larvae are of any size in the natural pools, S. couchi larvae have metamorphosed or are in small aggregations in different parts of the pool, usually in very shallow water while S. bombifrons are in deeper water. Thus in the natural pools, S. couchi larvae would rarely encounter the growth inhibiting influence of S. bombifrons larvae 30 days old.

The possibilities exist that S. bombifrons larvae might produce more growth inhibiting material at a larger size, and that selection has favored the rapid development of S. couchi in temporary pools. S. couchi larvae develop so rapidly that they would rarely come under the influence of S. bombifrons larvae.

Table 29. The effect of water crowded by 12 large Scaphiopus bombifrons larvae from Pool 4, Cleveland County, on the growth of Scaphiopus couchi larvae from Tipton, Tillman County. Experiment lasted from 9 June 1970 to 13 June 1970. Number of larvae is indicated in parentheses.

Species Tested	Sample Size	Total Weight in Grams Start	Finish
S. couchi	3a Control (4)	0.3810	1.0500
		0.3810	0.1800
S. couchi	3b Control (4)	0.3810	0.6517
	3b Assay (4)	0.3810	0.2837
		CONTROL (8)	1.7017
		ASSAY (8)	0.4637

5. Richard Wassersug (pers. comm. and in manuscript) has used an "index of inhibition" equal to the final weight of the control minus the final weight of the assay over the final weight of the control minus the initial weight of the control. The control and assay groups of larvae always started with the same weight and numbers of larvae. He calls his index I and the properties of this index are as follows: $I=0$ if no inhibition and both groups grow equally well; $I=1$ if total inhibition and the assay group does not grow at all; $I>1$ if the assay group loses weight: $I<0$ if the assay group actually gains more weight than the control; $0<I<1$ if inhibition other than total inhibition has occurred. Wassersug has carried out no experiments of his own on growth inhibition, but used this index to reanalyze the work of Licht (1967).

I have used the "index of inhibition" to analyze my data (Figure 11). According to the index, S. h. hurteri and S. bombifrons from Cleveland Co. were the least inhibited while S. bombifrons and especially S. couchi from Tillman County were greatly inhibited. This index would be useful in comparing inhibition in larvae of the same age, but tends to give the wrong picture when larvae of different ages and sizes are compared. An example is S. h. hurteri in my experiment. These larvae were large when the experiment was initiated and did not show the weight effects of inhibition, even though they were greatly inhibited on the basis of observations.

6. Licht (1967) reported that the effects of crowding occurred at all ages of growth, but the young larvae often yielded more pronounced results.

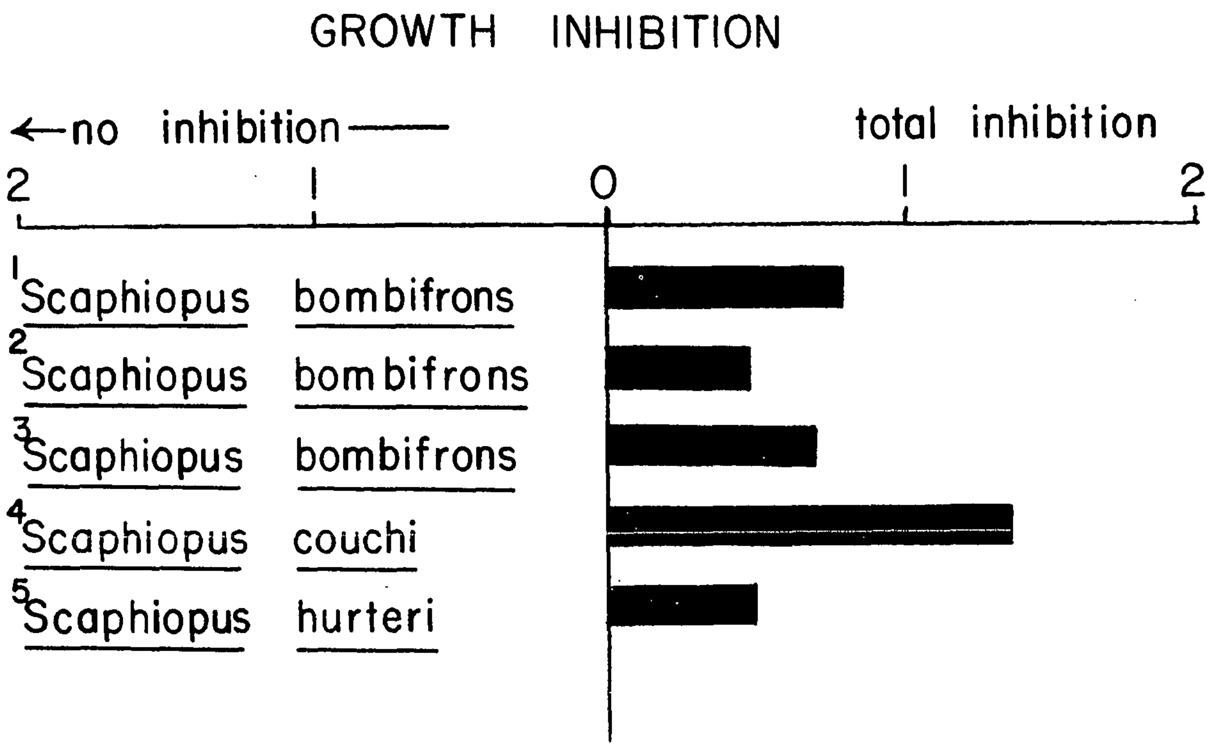


Figure 11. Graphical representation of growth inhibition using an "index of inhibition". The "index of inhibition" is equal to the final weight of the control minus the final weight of the assay over the final weight of the control minus the initial weight of the control. The salient properties of such an index (I) are as follows: I=0 if no inhibition and both groups grow equally well; I=1 if total inhibition and the assay group does not grow at all; I>1 if the assay group loses weight; I<0 if the assay group actually gains more weight than the control.

[1] S. bombifrons from Pool 12, Tillman Co.
Water conditioned by S. bombifrons from Pool 4, Cleveland Co.

[2] S. bombifrons from Pool 4, Cleveland Co.
Water conditioned by S. bombifrons from Pool 4, Cleveland Co.

[3] S. bombifrons from Pool 4, Cleveland Co.
Water conditioned by S. h. hurteri from Pool 3, Pottawatomie Co.

[4] S. couchi from Pool 12, Tillman Co.
Water conditioned by S. bombifrons from Pool 4, Cleveland Co.

[5] S. h. hurteri from Pool 2, Cleveland Co.
Water conditioned by S. bombifrons from Pool 4, Cleveland Co.

I have found this to be true from my data. One day old larvae showed the effects of inhibition much more than older larvae. Many species would have to lose weight in order for inhibition to be significant if they are used at an age when they have reached a threshhold in weight gain. This would be no problem with young rapidly growing larvae. There is also reason to believe that larvae of different ages of development very either in their production of the inhibitory factor or their sensitivity to it. There is also the possibility that the sensitivity of inhibition is proportional to the rate of weight gain. Thus, a younger and faster growing larvae would be more sensitive to inhibition. Someone doing future studies should use larvae of all the same developmental stages to condition the water and also to test for inhibition.

This data on Scaphiopus raises the question as to whether growth inhibition might be a reason for species segregation in pools. An example would be S. couchi and S. bombifrons in the same pools. But my data shows that S. bombifrons is inhibited by water in which S. bombifrons has been swimming. Aggregations would tend to put larvae together and make it much easier to obtain the inhibitory substance from the fecal material of other members of the aggregation.

I also question the validity of testing species for inhibition that never occur together in the same pools. Natural selection has kept many of these larvae from every occurring together. This points out the need for field studies to determine what species occur together and what age groups of larvae occur together in the same pools.

My experiments and those of Licht (1967) and others have all been done in the laboratory. The existence of the growth inhibiting substance in larvae under natural conditions has not been reported. Thus if the inhibitory substance is a laboratory phenomena, it would have no relevance to natural populations of anuran larvae.

But growth inhibiting substances do occur in natural populations and growth inhibition may be important in natural pools. In 1969, I (Black, 1969) reported on the ethoecology of _Bufo americanus charlesmithi_ larvae in Pool 1. In April, 1969, larvae of _B. a. charlesmithi_ and _Pseudacris streckeri_ occurred in large numbers throughout the Pool. By 13 April the pool had become quite small and little food appeared available for larvae. _B. a. charlesmithi_ larvae were aggregated in the deepest depressions of the pool.

Large _P. streckeri_ larvae were few in number but were also on the bottom of the pool. Smaller larvae of _P. streckeri_ were dead and dying. _B. a. charlesmithi_ and the large _P. streckeri_ larvae were eating the dead _P. streckeri_ larvae. The dead and dying larvae were emaciated and the head was the largest part of the body. Their guts were empty of food but _did contain the cells associated with inhibited growth in crowded anuran larvae_ (see Fig. 1 in Licht (1967) for photograph of cell). It appears that the _P. streckeri_ larvae had inhibited growth due to a growth inhibiting substance produced by larvae of _B. a. charlesmithi_ and/or _P. streckeri_. The loss of these larvae meant the survival of other larvae. Competition for the limited food and water was reduced and the dead larvae themselves were food. Growth inhibiting substances could be of value for survival of some species of larvae where competition occurs during the larval stage. Growth retardation in one species would allow more effective utilization of the aquatic environment by other species to allow some to metamorphose rather than all to perish.

CHAPTER XII

SURVIVAL OF *SCAPHIOPUS BOMBIFRONS* LARVAE OUT OF WATER

Introduction

The hardiness and rapid developmental rate of *Scaphiopus* larvae is well known and has been discussed in the preceeding chapters. Bragg (unpubl.) states: "Even those (anuran larvae) in Oklahoma of actual terrestrial habits (as in *Bufo* and *Scaphiopus*) die rather quickly when exposed to bright sunshine in summer except as they are able to compensate water loss by absorption from moist earth". He later states: "Actually no tadpoles in Oklahoma are known or suspected to be adapted to withstand *complete loss* of water from a pool and only those of *Scaphiopus* and possibly *Gastrophryne* have developed obvious adaptations for surviving. This is through hastened development".

The following observations on the survival of *S. bombifrons* larvae in rapidly evaporating pools show further adaptations apparently not observed by Bragg for survival of *Scaphiopus* larve.

Methods

S. bombifrons bred in temporary pools surrounding Tipton, Tillman County, on 15 May 1969. Many of these pools were dry by 23 May and their *Scaphiopus* larvae dead. On 28 May other pools had dried and their basins were covered with dead and decomposing larvae. Written and photographic observations were made on larvae stranded completely out of water and all temperatures were recorded with a Schultheis thermometer. A larva was considered dead when its mouth stopped opening and closing.

Results

On 28 and 29 May, observations were made in Pool 12 on the survival of larvae of S. bombifrons when all water in the pool had disappeared through evaporation and seepage leaving the larvae stranded completely out of water on the mud in the direct sun. These larvae appeared to be in Stage 30 of Gosner (1960).

14:30 hr., 28 May: Thirty-eight larvae were stranded completely out of water on wet mud directly in the sun. All were covered with mud from thrashing movements in the last remaining water. Most of the larvae were in a solid single-layer mass, but others were scattered around the edges of the main mass of larvae (Figure 12). The air temperature was 36.2 C and the temperature on the larval mass was 31.0 C.

17:15 hr., 28 May: Most of the larvae were still alive. Their exposed surfaces were dry and cracked and covered with mud. Red ants were tearing apart some of the scattered larvae. A larva was returned to nearby water where it recovered and swam away.

3:15 hr., 29 May: Thirteen hours later five of the original larvae were alive. The five live larvae were in the middle of the large mass. The temperature was 20.0 C on the larvae.

10:15 hr., 29 May: A single larva in the very middle of the mass was still alive. Ants and flies covered all the larvae and ants were dragging some of the dead larvae away. The temperature was 30.4 C on the live larva. Its mouth was continually opening and closing. The dead larvae surrounding it were decomposing.

13:10 hr., 29 May: The last larva was dead. The dorsal surface of it was dry and cracked while the venter was wet on the mud. The temperature was 35.8 C on the larva and 35.2 C on the mud under the larva. A single larva survived almost 20 hours completely out of water on wet mud.

This preceding account was not a rare occurrence as will be illustrated by the following example in Pool 20.

19:30 hr., 28 May 1969: Larvae of S. bombifrons had been out of water most of the day and all that remained was a pool of wet mud and larvae. Out of this moving mass of mud and larvae came metamorphosing larvae in early Stage 42 (Gosner, 1960). All metamorphosing larvae were covered with mud as they struggled from the mass and across the dry cracked ground to crawl or dig under any object to find a moist cool substrate. Many died not far from the pool. Under some pieces of cardboard and in tall grass, over 37 newly metamorphosed S. bombifrons were found.

9:15 hr., 29 May: The temperatures stayed warm all night and all larvae oriented themselves so that their mouths were at the surface of the mud (Figure 13). The top of the mud was composed of four to five larval mouths per square centimeter; the total mass was approximately 42 by 50 cm. The temperature on the mass was 27.2 C.

Figure 12. Thirty-eight larvae of *Scaphiopus bombifrons* isolated completely out of water on wet mud directly in the sun. Pool 12, Tillman County, Oklahoma, 28 May 1969.

Figure 13. Mass of *Scaphiopus bombifrons* larvae in Pool 20 (Burrows Pool), Tillman County, Oklahoma, 29 May 1969. This photograph looks directly down on larvae covered with dry mud. Each circular object in the photograph is an oriented larval snout at the surface of the mud. The surface of the mud was composed of four to five larval snouts per square centimeter.

Figure 12

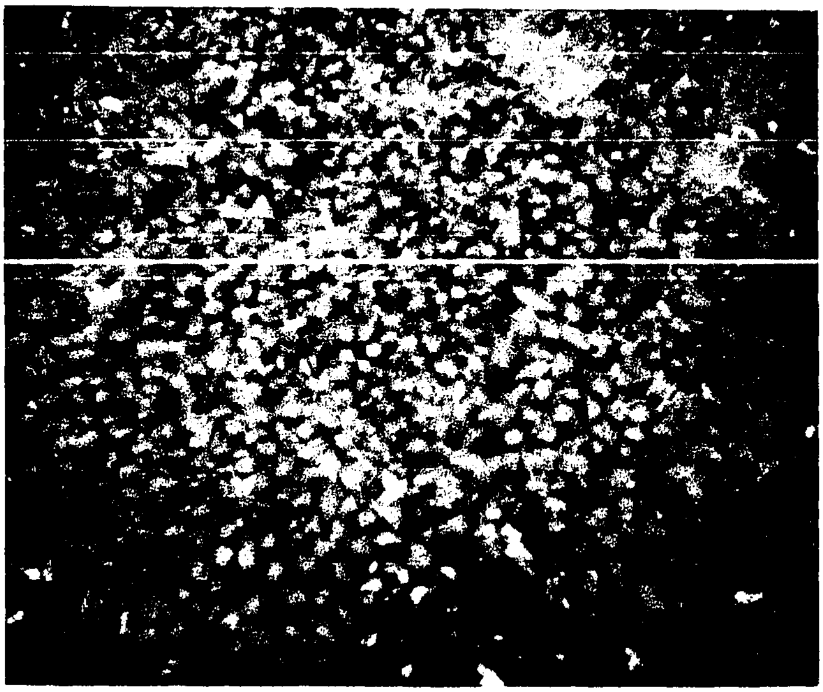


Figure 13

13:30 hr., 29 May: Upon approaching the pool area there was no evidence of any water, mud or larvae. If one were quiet you could hear a continuous clicking sound coming from the opening and closing of the larvae's mouths and the clicking together of their labial teeth. No eyes could be seen as there was a hard mud covering over all the larvae and only their opening and closing mouths were exposed. The temperature was 37.4 C on top of the mass. Occasionally the dry mud would crack and a metamorphosing larva would crawl out and attempt to make it to the grass. If the dry mud cover was broken into, beneath was a solid mass of wet mud and larvae. The orientation upwards of their mouths, and the formation of a dry mud cover had served to form a seal over the remaining moisture and thus give the larvae additional time to develop and metamorphose.

Scaphiopus larvae in Oklahoma, react quite differently in a quickly disappearing pool than do other frogs and toads. Larvae of *Rana*, *Pseudacris* and *Bufo* inhabiting temporary pools in Oklahoma remain on the bottom of the pools or swim slowly in whatever water remains. Even when only enough water remains to cover the larvae, they remain more or less motionless. Some will swim rapidly when disturbed and make the water turbid, but most do not stir up the remaining water and are found dead on the mud surface with *no mud covering them*. Small isolated pools with *Rana* and *Bufo* larvae have water with a high percentage of light transmittance indicating little stirring up of the water and pool basin by the larvae.

S. bombifrons larvae seldom quit moving and the water in remaining depressions is usually quite turbid. As the water level decreases more and more through evaporation and seepage, larvae are soon moving in a liquid mud and through these movements the remaining water and bottom materials are continually mixed until only soft mud up to two centimeters deep can remain. S. bombifrons larvae are completely covered with mud by the time all visible water has disappeared. The covering of mud as indicated by my observations, often means survival for those larvae near metamorphosis.

The effect of S. bombifrons movements in temporary pool water is indicated in Table 30. Turbidity is greater in rapidly evaporating waters with larvae than in water without larvae. This turbidity is directly related to movement and number of S. bombifrons larvae.

Table 30. Turbidity in water containing and not containing larvae of S. bombifrons. Measurements of turbidity in Jackson Turbidity Units (JTU) and percentage light transmittance (% Trans.).

	Pool 19 (17 June 1969)		Pool 18 (28 May 1969)	
	JTU	% Trans.	JTU	% Trans.
Larvae absent	125	68.2%	330	37.5%
Larvae present	500	21.0%	500+	0.0%

There are many possibilities as to how Scaphiopus larvae might survive under the conditions of a rapidly evaporating pool, excess heat, and low oxygen values, all of which commonly occur together.

1. Bragg (1965) reported that when the water level in a pool becomes very low small groups of larvae stop feeding and move their tails in such

a way that a depression is formed in the mud of the pool's basin. Bragg called these scooping aggregations and their function was to cut down the rate of evaporation through lessening the amount of surface exposed to the action of sun and water and give Scaphiopus larvae additional time to metamorphose.

2. Unpublished and incomplete research by a student of A. N. Bragg, indicated that lungs develop at an early stage in Scaphiopus larvae. The air bubble snatched from the surface would be pressed back through the glottus into the lungs. Lungs would enable these larvae to survive in temporary waters where oxygen depletion frequently occurs (Appendices I and II). Lungs would also adapt them for the utilization of atmospheric oxygen when the water has evaporated and the larvae are stranded out of water as discussed in this section.

3. All larvae stranded out of water had at least one side of their body surface in contact with a moist substrate. This should enable them to cutaneously absorb moisture and perhaps oxygen through cutaneous respiration.

4. The crowding effect of larvae in the last remaining water and remaining crowded together after all water has evaporated, would reduce the surface area exposed and reduce evaporation. Being crowded together, has the effect of reducing oxygen consumption as suggested by Gehlbach's (1969) study on Ambystoma tigrinum.

CHAPTER XIII

DISCUSSION

There has always been the question among students of the genus *Scaphiopus* as to why spadefoot toads use temporary water for breeding and development of larvae, and then only certain temporary pools. There is also the question of how spadefoots can determine if a pool is temporary. Bragg (1964) hypothesized that spadefoots ready to breed must receive sensory cues either from (a) temporary water which attracts them or (b) from permanent water which repels them, and that (c) these cues are more likely chemical than physical in nature; and that (d) permanent water often smells different to humans than does temporary water; and that (e) it is likely that it also does to spadefoots.

My observations lend support to the hypothesis that behavioral mechanisms are more important than the chemistry of water in determining what temporary pools are utilized, whereas chemistry of the water and predators are more important in determining survival of the species so that it can breed in temporary waters.

Behavioral mechanisms are more important than chemistry of the water because adult spadefoots were found to breed in temporary waters where the chemistry was not suitable for survival of larvae. Non-survival of larvae occurred because of oxygen dropping below 1 ppm which would not support the livelyhood of the eggs or where the pH of the water was so low that it increased the solubility of iron so that the eggs did not hatch.

Both of these chemical factors are common experiences for operators of fish hatcheries (H. P. Clemens, pers. comm.).

Temporary pool environments have few pool predators for Scaphiopus in so far as the water is there only for a short period, not usually long enough to attract predators. Also temporary pools did not support a fauna to attract many predators by providing them with a needed food supply. These pools are in existence after seasonal rains when many of them exist and make it more difficult for predators to focus on any particular pool. Scaphiopus have been seen to breed on one occasion in a permanent pool which indicates that they will breed in waters other than temporary pools. Spadefoots breeding in permanent pools would be most likely to fall prey to the larger fish and other predators that accumulate around permanent water, thus predation in these areas would be sufficient to deplete the populations. Aggregational behavior of spadefoot larvae would make them an obvious target for predator fish and this is added reason for them to be unsuccessful in the permanent pool environment.

Temporary pools offer several advantages to the animal that can adapt to this environment. The amphibian larva is the largest grazer and has little or no competition. Larval spadefoots move continuously securing food and are adapted to feed on accumulated organic matter (mostly vegetable) on the bottom of these pools of which there is plenty and so the animal is not faced with the problem of fluctuating food supplies like so many other animals. They are also predaceous on any small creature and if one of their own dies, it is immediately eaten.

Another problem that young animals of egg-laying species face is the suitability of temperatures for their development. The spadefoot has adapted itself to use temporary pools which are shallow and often protected from the wind with the result that they are considerably warmer than permanent pools in the same area at the time of breeding. The temperature for hatching and development needs to be between 12° and 33°C. If it is lower than this, the eggs take too long to develop and are lost. If temperatures are too high, a number of developmental anomalies appear or hatching does not even occur. Many temporary pools, but not all, provide a temperature where eggs hatch within 24 hours, larvae begin feeding within 72 hours, and metamorphosis can occur in 10 to 46 days.

Another interesting evolutionary adpatation is the releasing mechanism for breeding which is the onset of spring rains accompanied by thunder and lightning, which result in the formation of temporary pools.

On the average, the dangers to the larval spadefoots in temporary pools necessitate special behavioral adaptations and these have developed to a marked degree. No behavior is so striking as that of aggregations in Scaphiopus larvae. Members of most species form asocial or social feeding aggregations through which cooperation they secure on the average more food for each individual than it could usually find alone. These aggregations also protect the larvae from the predatory attacks of beetle larvae and the cannibalistic forms of Scaphiopus larvae. Scooping aggregations and premetamorphic pods serve to cut down water loss through greatly reducing surface exposed to the action of wind and sun, which cause the rapid evaporation of temporary pools. Some feeding aggregations even take the form of active cannibalism based primarily on the attack upon the shrivelling tails of transforming larvae, this apparently speeding up metamorphosis.

Larval spadefoots also develop lungs at a very early stage thus adapting them further for a warm and rapidly evaporating pool where oxygen values commonly fall below 1 ppm. No larval anurans in North American are known to survive completely out of water, but I have observed that if a pool dries before larvae have metamorphosed, many are able to survive completely out of water for up to 20 hours, enabling many of them to successfully metamorphose. Survival out of water is possible only through the development of lungs at an early age, behavioral movements to cover larvae with an insulative and protective covering of mud, and crowding together in the last water, all these being adaptations for survival in the temporary pool environment.

Such distinctive and unusual behavior and other adaptations of Scaphiopus larvae and all phases of reproductive activity are adaptations which secure the survival of the greatest number of Scaphiopus species under the adverse conditions of their temporary pool environment. It is truly as the late A. N. Bragg describes: "of all the Amphibia, none are so surprising as the spadefoots".

SUMMARY

This research is the first investigation to characterize the ecological habitat of _Scaphiopus_ larvae and some of the behavioral mechanisms behind the formation of aggregations and methods of survival in temporary waters. Also described are aspects of the physico-chemical features of temporary pool waters and vertebrates and invertebrate associates and vegetation.

Temporary pools were chosen in Tillman County, Oklahoma, to study larvae of _Scaphiopus bombifrons_ and _Scaphiopus couchi_, and in Cleveland and Pottawatomie Counties, Oklahoma, to study _Scaphiopus holbrooki hurteri_. Thirty-one temporary pools were studied periodically from July, 1968, through July, 1972. The results of this investigation are as follows:

1. Temporary pool habitats of _Scaphiopus_ larvae in Oklahoma have an extremely variable physico-chemical environment. A number of properties were found to show intensive circumdiel variations and some even showed large differences among locations within a pool at one time.

The magnitude of the spatial and short-term temporal variations in the environment of these small pools is an important consideration in taking measurements. The common procedure of measuring limnological properties at one position, usually in the middle of the pools, is not adequate for understanding the environmental conditions surrounding the pool organisms. Only detailed studies with extensive sampling will provide

a workable understanding of the environment faced by Scaphiopus larvae and other inhabitants of temporary pools.

2. Chemical features of waters in temporary pools correlated in certain aspects with the chemistry of the soil in pool basins. This was most apparent for pH and iron in Pool 3.

3. Phyllopod and cladoceran crustaceans were most abundant numerically during the existence of temporary pools in southwestern and central Oklahoma. Hydrophilid beetle larvae also were common and may have constituted the principle predator of temporary pools.

4. Some temporary pools in central Oklahoma were used as breeding places by at least nine different amphibians (especially S. h. hurteri, Bufo americanus charlesmithi, Hyla versicolor, Pseudacris streckeri and Rana pipiens), while those in southwestern Oklahoma were used primarily by S. bombifrons and S. couchi (as well as Bufo compactilus speciosus).

5. Aquatic plants are an important part of the temporary pool environment. Pools in central Oklahoma were characterized by true aquatic plants such as Cyperus virens, Cyperus ovularis, Juncus diffusissimus, Polygonum hydropiperoides, Eleocharis obtusa and Eleocharis Engelmannii. The only true aquatic plant collected in Tillman County temporary pools was Marsilea mucronata with the terrestrial plants, Polygonum pensylvanicum, Coreopsis tinctoria and Helianthus petiolaris, frequently occurring in dense growths in the pool basins.

6. The average rainfall for 57 choruses of S. bombifrons in Oklahoma was 1.393 ± 1.059 inches, ranging from a low of 0.05 to a maximum of 6.07 inches.

The average rainfall for 31 choruses of _S. h. hurteri_ was 1.832 $\pm$ 1.669 inches, ranging from a low of 0.03 to a maximum of 6.07 inches.

7. Of the 59 minimum-maximum temperature records of _S. bombifrons_, the mean minimum was 59.05 $\pm$ 6.834 F, the mean-maximum was 79.932 $\pm$ 8.986 F. Of the 31 minimum-maximum temperature records of _S. h. hurteri_, the mean-minimum was 55.451 $\pm$ 7.338 F, the mean-maximum was 76.032 $\pm$ 6.600 F.

8. Larvae of _S. couchi_ hatch in about 12 hours after depostition, whereas those of _S. bombifrons_ hatch within 24 hours. _S. couchi_ larvae metamorphose in about 13 days whereas _S. bombifrons_ larvae take from 18 to over 30 days to metamorphose. Eggs of _S. h. hurteri_ frequently take two days to hatch, and larval developmental rate is quite variable with metamorphosis occurring in 10 to 21 days.

9. Low pH, alkalinity, and the oxygen dropping very low at night create an unfavorable habitat for _Scaphiopus_ larvae in Oklahoma temporary pools. These characteristics can cause complete loss of all eggs prior to hatching as happened in Pools 3, 12, 15 and 20. Most successful hatching in southwestern Oklahoma temporary pools occurred in those pools that were shallow and laid in an east to west direction.

10. Experimental data on the development of visual attraction in larvae of _S. bombifrons_, _S. couchi_ and _S. h. hurteri_ indicated that aggregational behavior does not appear immediately after hatching but develops gradually over a period of several days. During this development, responses occur between larvae and eventually parallel orientations between larvae develops. The development of larva to larva responses, and then parallel orientation leads to the development of aggregations, probably when the visuo-motor co-ordination becomes more highly developed in the larvae.

An important aspect of aggregational behavior in Scaphiopus larvae is that it is an interaction between larvae and mutual responses from each larva are required to maintain an aggregation. Even though these larvae are attracted to an aggregation, they may need a certain amount of experience (learning?) before they are able to orient successfully. It is possible that early contact with others of its own species, may well be the essential element, influencing the later establishment of schooling and podding behavior, and that there may or may not be a critical time period.

11. On the basis of experiments in aquaria compared with data from limited observations in central Oklahoma temporary pools, a hypothesis was formed on the causitive factors in formation of feeding aggregations in S. h. hurteri. These factors involve the swimming movements by which the larva or larvae discovering the food create a "sign stimulus" onto other larvae; larvae recognize this swimming activity and pattern "sign stimulus" and form aggregations as they find the food and begin to feed.

12. Feeding aggregations, under some conditions, may act as protective devices against predation from beetle larvae or cannibalistic larvae of S. bombifrons.

13. It is generally known (Allee, 1938; Rugh, 1934; Adolph, 1931) that the crowding to which an anuran larva is subjected by other individuals of its own or other species may have profound effects upon its growth processes. Licht (1967) discussed the effects of an inhibiting cell in the feces of anuran larvae. This inhibitor, which is non-specific, has been shown to be water-carried and involve an algal-like cell and may be transmitted from one species to another. Licht suggested that such large larval aggregations as reported

by Bragg (1965b) in *Scaphiopus*, might result in stunted growth because of accumulated inhibitory substances.

My experimental data indicated the following:

a. Larvae of *S. bombifrons* are inhibited in water conditioned by *S. bombifrons* larvae.

b. Larvae of *S. bombifrons* are inhibited in water conditioned by *S. h. hurteri* larvae.

c. Larvae of *S. h. hurteri* are inhibited in water conditioned by *S. bombifrons* larvae.

d. Larvae of *S. couchi* are inhibited in water conditioned *S. bombifrons* larvae.

14. The hardiness of *Scaphiopus* larvae is well known, but it had not been reported that some can survive completely out of water on wet mud. A single larva of *S. bombifrons* was observed in Pool 12 to survive almost 20 hours completely out of water. Other larvae were observed to orient in a supine position with their mouths upward. A dry mud cover formed over them as the pool dried; the dry mud cover appeared to serve as a "seal" to additional moisture escaping and provided that additional time for the larvae to metamorphose.

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APPENDIX I

PHYSICO-CHEMICAL FEATURES OF WATERS FROM TEMPORARY POOLS IN SOUTHWESTERN AND CENTRAL OKLAHOMA

Appendix I

Physico-chemical features of waters from temporary pools in southwestern and central Oklahoma

The analyses conducted and the procedures followed for chemical determinations are listed below.

1. Phenolphthalein and Total Alkalinity were measured as ppm $CaCO_3$.
2. Chloride was determined by the Mercuric Nitrate Method and measured as ppm Chloride.
3. Hardness (Calcium) was determined by the EDTA Method in ppm $CaCO_3$.
4. Iron was determined by the 1,10-Phenanthroline Method (using Ferro-Ver Powder) and measured in ppm Iron.
5. Nitrate Nitrogen was determined by the Cadmium Reduction Method (Modified Diazotization [1-Naphthylamine-Sulfanilic Acid] Method) and read as ppm Nitrogen.
6. Nitrite Nitrogen was determined by the Diazotization Method (1-Naphthylamine-Sulfanilic Acid) and read in ppm Nitrite Nitrogen.
7. Dissolved Oxygen was determined by the Modified Azede-Winkler Method with Drop Count Titration (using PAO) and read in ppm Dissolved Oxygen.
8. pH was determined by use of a Wide-Range Indicator.
9. Ortho-Phosphate was determined by the StannaVer Method and read as ppm Orthophosphate.
10. Turbidity was measured in Jackson Turbidity Units, Formazin Standard, and read in Jackson Turbidity Units.

Physico-chemical features of Pool 1, Cleveland Co., Oklahoma

1969

	17-I	23-I	4-II	13-II	18-II	25-II	9-III	11-III	16-III	20-III	28-III	1-IV
M-O Alk.	75.0		35.0	75.0	50.0	48.0	65.0	////	115.0	120.0	////	42.0
Phen. Alk.	00.0		00.0	00.0	00.0	00.0	00.0	////	00.0	00.0	////	00.0
Cal. Hard.	45.0		////	////	////	30.0	////	////	////	////	////	////
TDS	////		////	////	////	////	////	////	////	////	////	////
pH	6.85		////	8.98	7.23	8.40	4.95	////	7.85	7.65	7.29	7.75
Oxygen	8.4		8.0	9.5	15.0	9.5	////	11.0	11.0	////	////	9.0
Turbidity (JTU)	////	DRY	////	170.0	320.0	345.0	155.0	////	100.0	78.0	280.0	195.0
% Trans.	54.0		21.2	60.0	35.5	35.0	63.0	////	75.0	81.0	42.0	55.5
Iron	1.8		////	////	0.5	////	////	////	0.27	////	0.62	0.78
Nitrate	////		////	////	8.8	////	////	////	////	////	////	////
Ortho-P	////		////	////	0.09	////	0.16	////	////	////	////	0.14
Meta-P	////		////	////	0.05	////	0.09	////	////	////	////	0.03
Surface °C / Bottom °C	11.6 / 11.5		5.8 / 6.6	8.2 / 7.9	//// / ////	18.6 / 14.5	13.5 / 13.0	1.8 / 3.38	21.9 / 21.7	//// / ////	//// / ////	22.5 / 22.3

Pool 1, Cleveland Co., Oklahoma. cont.
1969

	1-IV	4-IV	6-IV	8-IV	10-IV	12-IV	13-IV	15-IV	17-IV	24-IV	3-V	11-V	18-V
M-O Alk.	42.0	90.0	////	124.0	132.0	170.0	////	200.0	30.0	100.0	140.0	85.0	107.0
Phen. Alk.	00.0	00.0	////	00.0	00.0	00.0	////	00.0	00.0	00.0	00.0	00.0	00.0
Cal. Hard.	40.0	////	////	////	90.0	110.0	////	120.0	////	57.0	////	49.0	69.0
TDS	////	////	////	////	////	////	////	////	////	////	////	////	////
pH	7.75	8.10	////	7.80	////	8.48	////	////	////	7.33	8.20	7.50	7.33
Oxygen	9.0	////	9.0	8.0	8.3	6.0	5.5	0.5	////	7.0	7.0	////	7.0
Turbidity (JTU)	195.0	320.0	////	360.0	150.0	275.0	////	500.+	500.+	500.+	380.0	415.0	182.0
% Trans.	55.5	38.0	////	25.0	64.0	44.0	////	23.0	0.5	13.5	32.5	29.0	57.7
Iron	0.78	0.60	////	0.55	0.40	0.32	////	////	////	0.55	0.52	0.60	0.60
Nitrate	////	////	////	2.0	////	1.5	////	////	////	1.25	////	5.5	0.0
Ortho-P	0.14	////	////	////	////	0.12	////	////	////	0.23	////	0.08	0.11
Meta-P	0.03	////	////	////	////	0.40	////	////	////	0.07	////	0.16	0.02
Surface °C / Bottom °C	22.5 / 22.3	//// / ////	14.4 / 13.3	20.25 / 19.90	//// / ////	//// / ////	//// / ////	29.9 / 29.6	//// / ////	15.2 / 14.1	27.8 / 26.9	//// / ////	16.2 / 16.4

Pool 1, Cleveland Co., Oklahoma. cont.
1969

	20-V	27-V	1-VI	15-VI	21-VI	27-VI	28-VI	27-VII	3-VIII	30-VIII	11-IX	16-IX
M-O Alk.	////	80.0		50.0	120.0	210.0		48.0	105.0	60.0		27.0
Phen. Alk.	////	00.0		00.0	00.0	00.0		00.0	20.0	11.0		00.0
Cal. Hard.	////	////		////	70.0	130.0		30.0	60.0	40.0		15.0
TDS	////	////		////	200.0	252.0		66.0	118.0	78.0		////
pH	////	////		7.60	8.53	7.50		7.44	8.91	9.25		////
Oxygen	9.0	13.0		6.0	////	////		////	10.0	////		////
Turbidity (JTU)	////	450.0	DRY	260.0	70.0	105.0	DRY	270.0	77.0	87.0	DRY	500.+
% Trans.	////	27.4		44.5	82.5	73.7		43.6	81.1	78.0		21.7
Iron	////	////		0.40	0.25	0.62		0.44	0.22	0.20		////
Nitrate	////	////		////	////	////		1.0	////	3.0		1.7
Ortho-P	////	////		////	////	////		0.05	////	0.04		0.098
Meta-P	////	////		////	////	////		0.16	////	0.11		0.000
Surface °C / Bottom °C	32.6 / 32.1	34.8 / 32.5		30.30 / 25.32	38.10 / 38.05	//// / ////		//// / ////	39.40 / 39.25	//// / ////		//// / ////

Pool 1, Cleveland Co., Oklahoma. cont.

1969

	19-IX	20-IX	24-IX	30-IX	13-X	21-X	1-XI	13-XI	29-XI	10-XII	23-XII	24-XII
M-O Alk.	////	54.0	55.0	100.0	40.0	82.0	98.0			50.0	75.0	75.0
Phen. Alk.	////	00.0	00.0	12.0	00.0	00.0	00.0			00.0	00.0	00.0
Cal. Hard.	////	30.0	38.0	68.0	25.0	46.0	57.0			30.0	49.0	52.0
TDS	////	70.0	75.0	////	46.5	////	128.0			72.0	105.0	109.0
pH	////	8.27	8.28	8.60	////	8.24	8.22			////	8.27	8.05
Oxygen	9.0	8.0	////	////	8.0	////	10.0			////	10.5	10.0
Turbidity (JTU)	////	190.0	123.0	98.0	500.+	185.0	245.0	DRY	DRY	452.0	175.0	177.0
%Trans.	////	56.0	69.5	75.0	11.7	57.2	48.5			27.2	58.5	58.5
Iron	////	////	0.29	0.33	////	0.28	0.33			////	0.25	0.13
Nitrate	////	////	////	////	////	2.2	////			5.0	////	////
Ortho-P	////	////	////	////	////	0.0	////			0.035	////	////
Meta-P	////	////	////	////	////	0.14	////			0.085	////	////
Surface °C	31.90	27.02	////	////	16.3	////	19.35			////	13.8	8.53
Bottom °C	26.65	24.05	////	////	15.6	////	19.50			////	13.7	8.50

Pool 1, Cleveland County, Oklahoma. cont.

1970

	7-I	25-I	8-II	22-II	9-III	14-III	21-III	5-IV	9-IV	19-IV	24-IV	5-V	15-V
M-O Alk.	238.0	45.0	100.0				54.0	145.0	105.0	60.0	90.0	155.0	125.0
Phen. Alk.	00.0	00.0	0.05				00.0	00.0	00.0	00.0	00.0	00.0	00.0
Cal. Hard.	////	22.0	70.0				50.0	80.0	70.0	35.0	50.0	90.0	75.0
Chloride	////	5.0	12.5				9.0	10.0	10.0	7.5	5.0	10.0	13.0
TDS	310.0	47.8	127.0				105.0	////	150.0	80.0	110.0	190.0	145.0
pH	8.0	8.1	8.25	DRY	DRY	DRY	7.25	7.0	8.4	6.8	7.2	7.05	6.5
Oxygen	////	8.0	10.0				8.0	7.0	10.0	6.5	6.5	////	8.0
Turbidity (JTU)	500.+	38.0	210.0				415.0	500.+	220.0	500.+	500.0	500.+	500.+
% Trans.	0.0	90.2	52.7				28.7	9.5	51.3	4.0	23.5	8.0	11.1
Iron	////	0.06	0.19				////	0.20	////	////	////	////	////
Nitrate	////	6.0	////				3.0	////	////	5.5	2.0	3.0	3.0
Ortho-P	////	////	0.055				////	////	////	////	////	////	0.08
Meta-P	////	////	0.045				////	////	////	////	////	////	0.12
Surface °C	-0.5	14.5	15.10				6.5	30.05	26.05	24.55	20.75	19.40	27.30
Bottom °C	3.0	13.5	14.75				6.5	27.00	21.60	22.80	19.70	19.65	26.20

Pool 1, Cleveland Co., Oklahoma. cont.

1970

	22-V	5-VI	10-VI	22-VI	6-VII	9-VII	18-VII	14-VIII	24-VIII	2-IX	26-IX	14-X
M-O Alk.		////	164.0	131.0		40.0	105.0		65.0		50.0	59.0
Phen. Alk.		////	00.0	00.0		00.0	00.0		00.0		00.0	00.0
Cal. Hard.		////	100.0	69.0		20.0	60.0		44.0		30.0	32.0
Chloride		////	10.0	13.5		14.5	10.0		12.5		5.0	5.0
TDS		////	212.0	154.0		59.0	130.0		78.0		72.0	60.0
pH	DRY	////	8.47	8.36	DRY	7.73	7.58	DRY	7.6	DRY	7.59	7.95
Oxygen		9.0	////	9.0		////	////		11.0		11.0	8.5
Turbidity (JTU)		////	167.0	47.0		50.0	15.0		52.0		43.0	28.0
% Trans.		////	60.0	88.0		87.0	96.2		87.0		89.1	94.7
Iron		////	0.195	0.02		0.45	0.0		0.04		0.05	0.07
Nitrate		////	2.5	2.5		4.0	2.7		2.0		////	4.8
Ortho-P		////	////	////		////	////		0.02		////	////
Meta-P		////	////	////		////	////		0.14		////	////
Surface °C		29.0	24.6	34.5		////	////		33.55		////	23.25
Bottom °C		25.6	23.8	34.5		////	////		32.40		////	21.79

Pool 1, Cleveland Co., Oklahoma. cont.

1970

	15-X	20-X	3-XI	16-XI	30-XI	10-XII	31-XII
M-O Alk.	DRY	85.0	63.0	59.0	DRY	DRY	DRY
Phen. Alk.		10.0	00.0	00.0			
Cal. Hard.		40.0	40.0	35.0			
Chloride		5.0	21.0	30.0			
TDS		90.0	70.0	66.0			
pH		9.0	8.55	6.67			
Oxygen		////	9.0	9.0			
Turbidity (JTU)		2.0	48.0	41.0			
% Trans.		99.8	89.0	90.0			
Iron		0.02	0.02	0.03			
Nitrate		////	3.2	4.3			
Ortho-P		0.28	////	////			
Meta-P		0.01	////	////			
Surface °C / Bottom °C		24.9 / 24.9	11.0 / 11.6	16.4 / 15.1			

Physico-chemical features of Pool 2, Cleveland Co., Oklahoma
1969

	11-II	15-II	23-II	1-III	6-III	15-III	20-III	29-III	3-IV	6-IV	13-IV	17-IV
M-O Alk.	15.0	////	20.0	25.0	22.0	10.0	20.0	25.0	40.0	////	32.0	20.0
Phen. Alk.	00.0	////	00.0	00.0	00.0	00.0	00.0	00.0	00.0	////	00.0	00.0
Cal. Hard.	////	////	12.0	////	////	////	////	////	////	////	11.0	////
TDS	////	////	////	////	////	////	////	////	////	////	////	////
pH	6.5	6.41	6.88	6.48	6.4	6.68	6.48	6.5	6.91	////	6.6	////
Oxygen	7.0	////	6.5	6.5	8.0	////	6.0	6.0	6.0	6.0	////	////
Turbidity (JTU)	500.+	////	////	425.0	290.0	280.0	275.0	500.+	145.0	////	215.0	500.0
% Trans.	19.0	////	////	29.0	41.0	42.5	43.0	24.5	65.0	////	51.5	16.0
Iron	////	////	////	////	////	1.8	2.5	1.65	1.25	////	1.57	////
Nitrate	////	////	////	////	////	////	////	////	////	////	1.3	////
Ortho-P	////	////	0.03	////	0.06	////	0.07	////	////	////	0.07	////
Meta-P	////	////	0.03	////	0.025	////	0.07	////	////	////	0.05	////
Surface °C / Bottom °C	11.5 / 10.5	//// / ////	//// / ////	12.2 / 8.6	4.7 / 4.3	//// / ////	11.6 / 10.4	17.7 / 12.9	//// / ////	21.7 / 14.6	//// / ////	//// / ////

Pool 2, Cleveland Co., Oklahoma. cont.
1969

	20-IV	29-IV	4-V	7-V	8-V	15-V	27-V	31-V	6-VI	7-VI	8-VI	14-VI	20-VI	27-VI
M-O Alk.	////	45.0	50.0	18.0	////	60.0	45.0	50.0	170.0			15.0	25.0	30.0
Phen. Alk.	////	00.0	00.0	00.0	////	00.0	00.0	00.0	00.0			00.0	00.0	00.0
Cal. Hard.	////	////	28.0	////	////	35.0	////	22.0	87.0			////	11.0	10.0
TDS	////	////	////	////	////	////	////	////	////			////	133.0	138.0
pH	////	6.9	6.8	6.4	////	6.87	7.52	8.54	7.25			6.56	6.81	7.05
Oxygen	6.0	5.0	////	////	4.5	5.0	11.0	////	7.5	DRY	DRY	7.0	////	////
Turbidity (JTU)	////	100.0	88.0	500.+	////	115.0	120.0	17.0	120.0			200.0	77.0	14.0
% Trans.	////	75.0	78.0	195.0	////	71.5	72.0	95.5	70.5			54.5	81.0	96.2
Iron	////	0.63	0.75	////	////	////	1.12	0.94	1.63			0.85	0.72	1.15
Nitrate	////	////	1.8	////	////	1.0	////	0.0	2.5			////	////	////
Ortho-P	////	////	0.02	////	////	0.04	////	0.05	0.75			////	////	////
Meta-P	////	////	0.07	////	////	0.11	////	0.045	0.00			////	////	////
Surface °C	24.4	23.4	////	23.6	19.0	23.9	////	36.35	////			26.6	36.0	////
Bottom °C	16.2	16.5	////	////	////	20.9	////	35.95	////			////	34.5	////

Pool 2, Cleveland Co., Oklahoma. cont.

1969

	28-VI	30-VI	27-VII	3-VIII	11-IX	30-IX	13-X	21-X	31-X	13-XI	29-XI	23-XII
M-O Alk.	////						15.0	30.0	75.0			30.0
Phen. Alk.	////						00.0	00.0	00.0			00.0
Cal. Hard.	////						10.0	15.0	50.0			20.0
TDS	////						15.0	43.0	92.0			36.5
pH	////	DRY	DRY	DRY	DRY	DRY	////	////	////	DRY	DRY	7.9
Oxygen	9.0						////	////	////			////
Turbidity (JTU)	////						500.+	500.+	500.+			310.0
% Trans.	////						0.5	5.4	0.0			38.5
Iron	////						////	////	////			0.72
Nitrate	1.8						////	////	////			////
Ortho-P	0.0						////	////	////			////
Meta-P	0.045						////	////	////			////
Surface °C	33.1						////	////	////			////
Bottom °C	32.9						////	////	////			////

Pool 2, Cleveland Co., Oklahoma. cont.

1970

	14-I	22-II	9-III	14-III	21-III	7-IV	9-IV	10-IV	19-IV	23-IV	24-IV	8-V	15-V
M-O Alk.	DRY	DRY	DRY	DRY	30.0	30.0	30.0	38.0	25.0	////	35.0	////	60.0
Phen. Alk.					00.0	00.0	00.0	00.0	00.0	////	00.0	////	00.0
Cal. Hard.					20.0	20.0	20.0	22.0	20.0	////	25.0	////	36.0
Chloride					5.0	6.0	5.0	5.0	5.0	////	5.0	////	13.0
TDS					70.0	40.0	45.0	42.0	60.0	////	40.5	////	69.0
pH					7.2	7.1	////	////	6.9	////	7.0	////	6.4
Oxygen					////	8.5	8.5	10.0	////	7.0	////	5.0	8.5
Turbidity (JTU)					500.+	500.+	500.+	500.+	500.+	////	500.+	////	500.+
% Trans.					5.0	8.5	7.75	8.5	0.0	////	0.0	////	0.0
Iron					////	////	////	////	////	////	////	////	////
Nitrate					3.5	6.5	////	////	5.0	////	4.0	////	7.0
Ortho-P					////	0.075	////	////	////	////	////	////	0.02
Meta-P					////	0.075	////	////	////	////	////	////	0.42
Surface °C / Bottom °C					11.4 / 11.4	23.65 / 17.20	18.05 / 17.40	27.5 / 26.0	//// / ////	//// / ////	//// / ////	24.4 / 22.4	28.35 / 25.05

Pool 2, Cleveland Co., Oklahoma. cont.

1970

	22-V	24-V	25-V	29-V	10-VI	15-VI	18-VI	22-VI	30-VI	12-VII	24-VII	12-VIII
M-O Alk.	140.0	140.0		20.0	60.0	////	50.0	105.0				
Phen. Alk.	00.0	00.0		00.0	00.0	////	00.0	00.0				
Cal. Hard.	90.0	////		15.0	35.0	////	30.0	59.0				
Chloride	12.5	15.0		7.5	6.0	////	12.5	11.0				
TDS	162.0	162.0		22.0	95.0	////	61.0	142.0				
pH	5.65	7.6	DRY	////	////	////	////	8.1	DRY	DRY	DRY	DRY
Oxygen	////	////		////	7.0	7.0	////	11.0				
Turbidity (JTU)	340.0	270.0		500.+	500.+	////	500.+	45.0				
% Trans.	35.8	44.0		0.0	6.5	////	5.2	89.0				
Iron	0.15	0.10		////	////	////	////	0.075				
Nitrate	3.0	2.0		3.0	3.0	////	4.5	3.0				
Ortho-P	////	////		////	////	////	////	////				
Meta-P	////	////		////	////	////	////	////				
Surface °C / Bottom °C	//// / ////	//// / ////		//// / ////	//// / ////	37.4 / 27.1	//// / ////	35.2 / 35.1				

Pool 2, Cleveland Co., Oklahoma. cont.
1970

	24-VIII	2-IX	17-IX	25-IX	26-IX	14-X	15-X	20-X	3-XI	16-XI	10-XII	11-XII	23-XII
M-O Alk.	31.0	61.0		47.0	////	61.0		60.0	60.0	73.0	330.0		
Phen. Alk.	00.0	00.0		00.0	////	00.0		6.0	00.0	00.0	00.0		
Cal. Hard.	15.0	31.0		20.0	////	29.0		27.0	28.0	25.0	45.0		
Chloride	6.0	6.0		5.5	////	6.5		20.0	21.5	17.5	50.0		
TDS	32.3	72.0		////	////	57.0		58.0	64.0	78.0	425.0		
pH	7.39	7.28		7.69	////	7.35		8.83	8.52	7.85	6.55		
Oxygen	////	////	DRY	5.5	6.5	8.0	DRY	7.0	////	8.0	////	DRY	DRY
Turbidity (JTU)	70.0	3.0		52.0	////	28.0		8.0	50.0	143.0	500.0		
% Trans.	83.1	98.7		83.5	////	93.0		97.5	86.1	65.1	15.1		
Iron	0.05	0.00		0.03	////	0.11		0.0	0.01	0.04	////		
Nitrate	4.0	2.2		////	////	7.7		6.1	1.0	4.5	5.0		
Ortho-P	0.02	0.17		////	////	////		0.21	////	////	////		
Meta-P	0.08	0.00		////	////	////		0.00	////	////	////		
Surface °C	34.05	32.9		23.6	////	23.75		21.5	10.40	13.15	////		
Bottom °C	25.90	32.9		////	////	20.90		19.2	9.75	10.15			

Physico-chemical features of Pool 3, Pottawatomie Co., Oklahoma
1969

	23-I	6-II	11-II	15-II	21-II	1-III	6-III	18-III	29-III	6-IV	13-IV	17-IV
M-O Alk.	30.0	10.0	16.0	////	9.0	15.0	20.0	20.0	20.0	33.0	19.0	12.0
Phen. Alk.	00.0	00.0	00.0	////	0.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
Cal. Hard.	10.0	////	////	////	5.0	////	////	10.0	////	9.0	8.0	////
Chloride	////	////	////	////	////	////	////	////	////	////	////	////
TDS	////	////	////	////	////	////	////	////	////	////	////	////
pH	6.18	6.00	6.30	////	6.00	6.46	6.00	6.30	6.42	////	6.35	6.10
Oxygen	5.0	9.0	6.0	////	////	9.0	6.5	9.0	8.0	9.0	////	////
Turbidity (JTU)	////	440.0	330.0	////	490.0	295.0	180.0	500.0	500.+	500.+	200.0	500.+
% Trans.	81.0	47.5	35.0	////	25.5	40.0	58.5	24.0	10.5	5.5	55.0	7.5
Iron	0.78	1.39	////	////	////	////	////	1.5	1.2	////	1.35	////
Nitrate	////	////	////	////	////	////	////	////	////	////	1.3	////
Ortho-P	////	////	////	////	0.09	////	0.08	0.12	////	0.14	0.01	////
Meta-P	////	////	////	////	0.11	////	0.00	0.02	////	0.11	0.07	////
Surface °C	1.00	17.00	4.90	1.10	7.60	18.20	4.00	12.40	19.20	////	////	////
Bottom °C	3.00	12.10	4.90	2.50	6.60	15.10	4.35	9.50	14.30	////	////	////

Physico-chemical features of Pool 3, Pottawatomie Co., Oklahoma. cont.
1969

	20-IV	29-IV	4-V	7-V	8-V	15-V	27-V	31-V	5-VI	6-VI	10-VI	11-VI	14-VI
M-O Alk.	////	30.0	31.0	19.0	////	28.0	40.0	37.0	////	50.0	77.0		15.0
Phen. Alk.	////	00.0	00.0	00.0	////	00.0	00.0	00.0	////	00.0	00.0		00.0
Cal. Hard.	////	////	14.0	////	////	10.0	////	16.0	////	////	28.0		////
Chloride	////	////	////	////	////	////	////	////	////	////	////		////
TDS	////	////	////	////	////	////	////	////	////	////	////		////
pH	////	////	////	6.57	////	6.54	6.77	6.67	////	////	6.45		5.90
Oxygen	8.0	7.0	////	////	7.0	8.0	7.0	7.5	4.0	2.5	2.0	DRY	6.0
Turbidity (JTU)	////	340.0	420.0	500.+	////	180.0	180.0	240.0	////	348.0	230.0		280.0
% Trans.	////	36.0	28.5	15.5	////	58.0	58.3	48.9	////	35.0	50.0		42.0
Iron	////	0.875	0.82	0.53	////	////	1.0	0.53	////	////	1.19		0.85
Nitrate	////	////	2.0	////	////	2.0	////	0.0	////	0.0	////		////
Ortho-P	////	////	0.57	////	////	3.0	////	0.175	////	////	1.80		////
Meta-P	////	////	0.02	////	////	0.0	////	0.175	////	////	0.15		////
Surface °C	22.90	25.10	////	24.10	19.60	25.40	29.80	33.80	32.20	31.45	////		23.90
Bottom °C	14.40	////	////	////	////	22.60	////	32.75	28.52	28.30	////		21.50

Physico-chemical features of Pool 3, Pottawatomie Co., Oklahoma. cont.

1969

	21-VI	27-VI	30-VI	5-VII	27-VII	3-VIII	11-IX	24-IX	30-IX	13-X	21-X	31-X
M-O Alk.	30.0	50.0	68.0		65.0	57.0		21.0		10.0	20.0	25.0
Phen. Alk.	00.0	00.0	00.0		00.0	00.0		00.0		00.0	00.0	00.0
Cal. Hard.	15.0	12.0	29.0		22.0	25.0		7.0		5.0	10.0	5.0
Chloride	////	////	////		////	////		////		////	////	////
TDS	155.0	54.0	92.0		97.0	94.0		68.0		34.0	33.0	45.5
pH	6.63	6.36	6.82		6.62	6.72		6.22		////	6.42	////
Oxygen	////	5.0	1.0	DRY	////	5.0	DRY	////	DRY	6.0	////	8.0
Turbidity (JTU)	71.0	58.0	44.0		129.0	118.0		380.0		500.+	255.0	188.0
% Trans.	82.3	84.7	89.2		68.5	71.3		31.8		13.8	45.5	57.5
Iron	0.87	1.85	1.27		1.35	1.38		2.15		////	0.80	0.95
Nitrate	////	0.0	////		1.0	////		9.5		////	3.0	////
Ortho-P	////	0.13	////		0.175	////		0.23		////	0.15	////
Meta-P	////	0.02	////		0.165	////		0.00		////	0.00	////
Surface °C	35.70	29.50	23.40		29.30	34.90		////		16.65	////	14.40
Bottom °C	33.15	28.00	23.60		////	31.05		////		13.80	////	14.20

Physico-chemical features of Pool 3, Pottawatomie Co., Oklahoma. cont.

	1969						1970					
	13-XI	20-XI	29-XI	10-XII	23-XII	24-XII	10-I	11-I	17-I	8-II	22-II	1-III
M-O Alk.	13.0	25.0	26.0	20.0	25.0	15.0	80.0	45.0	14.0	54.0	32.0	50.0
Phen. Alk.	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
Cal. Hard.	9.0	10.0	10.0	5.0	10.0	10.0	40.0	20.0	5.0	21.0	13.0	20.0
Chloride	////	////	////	////	////	////	////	////	4.0	10.0	10.0	////
TDS	45.5	43.0	55.0	37.8	47.3	45.5	132.0	75.0	17.8	71.0	65.0	70.0
pH	////	////	////	6.40	6.44	6.37	7.05	5.88	6.45	6.70	6.65	6.88
Oxygen	////	////	////	////	4.0	4.0	////	0.0	5.0	8.0	6.0	6.0
Turbidity (JTU)	375.0	335.0	410.0	215.0	172.0	110.0	210.0	140.0	53.0	88.0	42.0	53.0
% Trans.	32.2	35.7	29.7	52.2	59.0	72.7	52.2	65.8	86.5	79.0	90.2	86.8
Iron	1.54	1.97	////	0.49	1.85	0.51	3.2	3.25	0.18	3.45	0.87	2.48
Nitrate	////	4.3	////	////	////	////	6.0	////	3.7	7.0	6.5	4.7
Ortho-P	////	0.075	////	////	////	////	////	////	0.003	0.08	////	0.11
Meta-P	////	0.535	////	////	////	////	////	////	0.140	0.04	////	0.00
Surface ^{o}C	////	11.95	9.0	////	11.45	6.45	////	0.5	1.9	15.75	7.5	18.9
Bottom ^{o}C	////	11.00	8.9	////	10.00	6.20	////	2.0	3.6	14.10	7.5	14.8

Physico-chemical features of Pool 3, Pottawatomie Co., Oklahoma. cont.
1970

	3-III	9-III	14-III	21-III	5-IV	7-IV	10-IV	18-IV	24-IV	15-V	22-V	29-V
M-O Alk.	////	50.0	50.0	20.0	52.0	42.0	45.0	34.0	50.0	50.0	60.0	15.0
Phen. Alk.	////	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0	00.0
Cal. Hard.	////	20.0	21.0	13.0	20.0	20.0	20.0	16.0	25.0	20.0	30.0	10.0
Chloride	////	10.0	////	7.5	5.0	5.0	10.0	5.0	5.0	10.0	22.5	10.0
TDS	90.0	70.0	82.0	48.0	////	53.0	70.0	50.0	60.0	65.0	110.0	19.5
pH	6.62	7.35	6.86	6.40	6.95	6.90	6.93	6.75	6.81	7.41	5.16	////
Oxygen	////	5.0	8.0	7.0	4.5	5.0	6.5	////	4.0	9.0	////	////
Turbidity (JTU)	////	110.0	97.0	149.0	178.0	102.0	240.0	260.0	350.0	187.0	330.0	490.0
% Trans.	////	72.5	74.5	63.5	59.0	74.0	48.0	44.0	34.0	57.0	36.4	25.0
Iron	////	2.4	0.85	0.20	0.30	0.72	2.25	1.1	////	1.52	0.85	////
Nitrate	////	4.5	4.0	1.0	0.0	5.0	////	3.0	2.5	1.5	4.0	3.0
Ortho-P	////	////	0.12	////	////	0.22	////	////	////	1.05	////	////
Meta-P	////	////	0.09	////	////	0.14	////	////	////	0.38	////	////
Surface °C	26.00	24.05	15.50	6.10	30.55	22.30	28.90	////	22.55	30.20	35.00	////
Bottom °C	20.30	22.10	13.30	5.85	21.20	17.20	27.05	////	18.70	28.60	30.20	////

Physico-chemical features of Pool 3, Pottawatomie Co., Oklahoma. cont.
1970

	5-VI	10-VI	22-VI	18-VII	24-VIII	2-IX	23-IX	26-IX	3-X	14-X	15-X	20-X
M-O Alk.	////	74.0	60.0	50.0	25.0		15.0	20.0		30.0		34.0
Phen. Alk.	////	00.0	00.0	00.0	00.0		00.0	00.0	0	00.0		00.0
Cal. Hard.	////	25.0	31.0	25.0	20.0		5.0	7.0		10.0		11.0
Chloride	////	10.0	17.5	12.5	12.0		5.0	5.5		7.5		9.0
TDS	////	121.0	82.0	79.0	51.0		25.0	18.0		28.0		26.9
pH	////	7.35	7.40	6.90	6.49		6.90	7.00		7.24		7.51
Oxygen	7.0	////	////	////	7.0		9.0	10.0		9.0		////
Turbidity (JTU)	////	75.0	119.0	72.0	78.0		75.0	93.0		85.0		16.0
% Trans.	////	82.0	69.8	81.7	81.0		81.2	76.1		79.1		95.7
Iron	////	0.32	0.25	0.045	0.02		0.08	0.05		0.05		0.00
Nitrate	////	2.5	4.5	2.2	1.9		////	////		4.5		4.2
Ortho-P	////	////	////	////	0.25		////	////		////		0.15
Meta-P	////	////	////	////	0.07		////	////		////		0.00
Surface ^{o}C	27.90	////	////	////	35.52		21.60	19.37		27.10		24.17
Bottom ^{o}C	22.40	////	////	////	31.60		////	19.30		19.55		20.15

Physico-chemical features of Pool 3, Pottawatomie Co., Oklahoma. cont.

	1970				1971
	3-XI	16-XI	10-XII	26-XII	5-I
M-O Alk.	31.0	////	////	30.0	28.0
Phen. Alk.	00.0	////	////	00.0	00.0
Cal. Hard.	21.0	////	////	////	15.0
Chloride	23.5	////	////	25.0	25.0
TDS	34.0	36.0	50.0	55.0	79.0
pH	7.28	////	////	6.97	7.00
Oxygen	8.0	7.0	////	////	////
Turbidity (JTU)	39.0	////	////	500.+	195.0
% Trans.	90.7	////	////	0.0	54.3
Iron	0.08	////	////	////	0.32
Nitrate	4.2	////	////	////	////
Ortho-P	////	////	////	////	////
Meta-P	////	////	////	////	////
Surface °C / Bottom °C	10.40 / 10.20	13.60 / 12.20	16.65 / 15.90	7.60 / 7.20	//// / ////

Physico-chemical features of Power Station Pool, Tillman Co., Oklahoma

	1969						1970							
	23-VII	2-VIII	15-IX	4-X	6-XI	9-XII	21-I	13-III	22-IV	30-IV	26-V	1-VI	9-VI	2-VII
M-O Alk.	50.0	38.0	31.0	37.0	35.0		9.0					53.0		
Phen. Alk.	////	////	////	////	////		////					////		
Cal. Hard.	33.0	20.0	20.0	20.0	22.0		2.0					33.0		
Chloride	////	////	////	////	////		5.0					5.0		
TDS	60.0	49.0	67.0	55.0	37.2		11.7					89.0		
pH	6.10	////	6.88	6.95	7.10		6.65					6.75		
Oxygen	////	////	////	5.0	////	DRY	////	DRY	DRY	DRY	DRY	////	DRY	DRY
Turbidity (JTU)	330.0	295.0	230.0	250.0	500.+		1.5					410.0		
% Trans.	36.7	40.3	49.5	46.5	9.0		95.8					29.0		
Iron	////	1.3	0.08	0.90	////		0.08					////		
Nitrate	////	////	////	////	////		6.2					////		
Ortho-P	////	////	////	////	////		////					////		
Meta-P	////	////	////	////	////		////					////		
Surface °C / Bottom °C	//// / ////	//// / ////	//// / ////	19.15 / 19.20	//// / ////		//// / ////					//// / ////		

Physico-chemical features of Power Station Pool, Tillman Co., Oklahoma
1970

	11-VIII	19-VIII	19-IX	3-X	1-XI	30-XII
M-O Alk.	35.0					
Phen. Alk.	00.0					
Cal. Hard.	15.0					
Chloride	21.5					
TDS	37.9					
pH	6.95					
Oxygen	////	DRY	DRY	DRY	DRY	DRY
Turbidity (JTU)	131.0					
% Trans.	67.7					
Iron	0.08					
Nitrate	////					
Ortho-P	0.30					
Meta-P	0.02					
Surface °C / Bottom °C	//// / ////					

Physico-chemical features of Donut Pool and Pool F, Cleveland Co., Oklahoma

	Pool F 1969		Pool F 1970					Donut Pool 1970	
	7-V	8-V	21-III	7-IV	21-IV	8-V	22-V	30-V	21-VI
M-O Alk.	////	////	25.0		30.0			75.0	200.0
Phen. Alk.	////	////	00.0		00.0			00.0	00.0
Cal. Hard.	////	////	15.0		15.0			50.0	111.0
Chloride	////	////	5.0		4.5			7.5	25.0
TDS	////	////	50.0		////			131.0	270.0
pH	////	6.38	6.33		7.02			7.65	8.05
Oxygen	////	////	8.0		////			////	////
Turbidity (JTU)	////	45.0	210.0		67.0			45.0	123.0
% Trans.	////	89.0	52.4		83.0			89.0	69.8
Iron	////	0.04	0.48		0.10			0.00	0.00
Nitrate	////	////	2.0		3.5			////	2.5
Ortho-P	////	////	////		////			////	////
Meta-P	////	////	////		////			////	////
Surface °C	17.25	19.80	9.30		////			////	////
Bottom °C	////	////	9.20		////			////	////

Physico-chemical features of Pools 4 and 5, Cleveland Co., Oklahoma

	Pool 4						Pool 5	
	1969				1970		1969	
	26-IV	27-IV	28-IV	2-V	16-V	29-V	28-IV	2-V
M-O Alk.	////	////	28.0	70.0	33.0	15.0	14.0	40.0
Phen. Alk.	////	////	00.0	00.0	00.0	00.0	00.0	00.0
Cal. Hard.	////	////	////	////	25.0	5.0	////	////
Chloride	////	////	////	////	7.5	5.0	////	////
TDS	////	////	////	////	39.0	17.0	////	////
pH	////	////	6.55	6.75	7.01	7.00	6.60	6.72
Oxygen	////	////	6.0	////	8.0	////	7.0	////
Turbidity (JTU)	////	////	310.0	250.0	500.+	300.0	225.0	110.0
% Trans.	////	////	39.0	46.5	2.5	39.0	51.0	72.5
Iron	////	////	0.90	0.87	////	0.30	0.85	0.58
Nitrate	////	////	////	////	////	9.2	////	////
Ortho-P	////	////	////	////	8.+	////	////	////
Meta-P	////	////	////	////	8.+	////	////	////
Surface °C / Bottom °C	13.0 / ////	17.0 / ////	//// / ////	//// / ////	//// / ////	//// / ////	//// / ////	//// / ////

Physico-chemical features of Little Axe Pools 6, 7 and 8, Cleveland Co., Oklahoma. 1969

	Pool 6			Pool 7	Pool 8
	7-V	8-V	27-V	7-V	7-V
M-O Alk.	90.0	72.0	69.0	42.0	27.0
Phen. Alk.	00.0	00.0	00.0	00.0	////
pH	6.89	6.39	6.25	6.00	7.05
Turbidity (JTU)	193.0	280.0	15.0	500.+	32.0
% Trans.	55.5	42.0	96.5	20.0	92.0
Iron	0.82	0.94	////	////	0.04
Surface °C	18.10	////	26.50	////	24.50

Physico-chemical features of Pool 11, Tillman Co., Oklahoma
1969

	28-III	10-V	23-V	28-V	29-V	7-VI	17-VI	23-VI	24-VI	1-VII	9-VII	23-VII	2-VIII
M-O Alk.		60.0	150.0	173.0	210.0		80.0	125.0	////	300.0	195.0	230.0	
Phen. Alk.		00.0	00.0	00.0	00.0		00.0	0.25	////	00.0	10.0	00.0	
Cal. Hard.		////	////	////	////		////	65.0	////	122.0	60.0	100.0	
Chloride		////	////	////	////		////	////	////	////	////	////	
TDS		////	////	////	////		////	160.0	////	690.0	875.0	447.0	
pH	DRY	6.55	7.95	8.36	7.70	DRY	7.53	9.30	////	8.38	9.12	7.51	DRY
Oxygen		4.0	7.0	8.0	8.0		7.0	10.0	3.5	11.0	10.5	////	
Turbidity (JTU)		500.+	33.0	58.0	37.0		205.0	5.0	////	0.0	17.0	20.0	
% Trans.		19.5	91.5	86.0	93.0		53.8	99.0	////	100.0	96.0	94.5	
Iron		////	0.48	0.48	1.52		0.45	0.22	////	0.00	0.02	0.00	
Nitrate		////	////	////	////		////	////	////	////	////	////	
Ortho-P		////	////	////	////		////	////	////	////	////	////	
Meta-P		////	////	////	////		////	////	////	////	////	////	
Surface °C		22.50	22.40	32.00	34.55		32.10	27.10	21.65	29.35	36.90	////	
Bottom °C		21.55	21.40	31.65	34.92		27.20	27.30	21.65	29.05	37.20	////	

Physico-chemical features of Pool 11, Tillman Co., Oklahoma

	1969				1970								
	15-IX	4-X	6-XI	9-XII	21-I	13-III	22-IV	30-IV	26-V	1-VI	9-VI	2-VII	11-VIII
M-O Alk.	70.0		80.0					45.0					60.0
Phen. Alk.	18.0		00.0					00.0					00.0
Cal. Hard.	31.0		40.0					25.0					33.0
Chloride	////		////					////					12.5
TDS	125.0		115.0					57.0					////
pH	9.90		8.43					6.85					6.99
Oxygen	////	DRY	////	DRY	DRY	DRY	DRY	////	DRY	DRY	DRY	DRY	////
Turbidity (JTU)	42.0		275.0					500.+					230.0
% Trans.	89.0		43.2					2.0					49.3
Iron	0.02		0.43					////					0.11
Nitrate	////		////					2.2					3.5
Ortho-P	////		////					////					1.98
Meta-P	////		////					////					0.00
Surface °C / Bottom °C	//// / ////		//// / ////					20.70 / 20.70					34.00 / 34.00

Physico-chemical features of
Pool 11, Tillman Co., Oklahoma
1970

	19-VIII	19-IX	3-X	1-XI	9-XII
M-O Alk.	110.0				
Phen. Alk.	00.0				
Cal. Hard.	60.0				
Chloride	106.5				
TDS	151.0				
pH	7.40				
Oxygen	6.0	DRY	DRY	DRY	DRY
Turbidity (JTU)	227.0				
% Trans.	50.0				
Iron	0.15				
Nitrate	2.2				
Ortho-P	1.98				
Meta-P	0.00				
Surface °C	33.50				
Bottom °C	33.50				

Physico-chemical features of
Long Swan Ranch Pool, Tillman Co., Oklahoma

	1969			1970		
	2-VIII	4-X	6-XI	11-VIII	19-VIII	19-IX
M-O Alk.	117.0	110.0	62.0	182.0		
Phen. Alk.	00.0	00.0	00.0	00.0		
Cal. Hard.	55.0	72.0	42.0	80.0		
Chloride	////	////	////	52.5		
TDS	////	170.0	112.0	295.0		
pH	6.70	7.32	7.66	7.24		
Oxygen	9.0	8.0	////	////	DRY	DRY
Turbidity (JTU)	500.+	50.0	180.0	28.0		
% Trans.	3.2	87.7	58.0	92.3		
Iron	////	0.14	0.44	0.08		
Nitrate	3.0	////	////	2.0		
Ortho-P	1.22	////	////	0.66		
Meta-P	2.0+	////	////	0.59		
Surface °C	31.30	////	////	////		
Bottom °C	////	////	////	////		

Physico-chemical features of Pool 12, Tillman Co., Oklahoma
1969

	28-III	10-V	23-V	28-V	7-VI	17-VI	23-VI	1-VII	9-VII	23-VII	2-VIII	15-IX	4-X
M-O Alk.		52.0	142.0	170.0		123.0		290.0	290.0	250.0		110.0	
Phen. Alk.		00.0	00.0	00.0		00.0		00.0	00.0	00.0		25.0	
Cal. Hard.		////	////	////		////		135.0	110.0	98.0		60.0	
Chloride		////	////	////		////		////	////	////		////	
TDS		////	////	////		////		710.0	725.0	////		160.0	
pH		6.42	8.42	9.25		7.75		8.27	8.53	8.15		9.70	
Oxygen	DRY	5.0	9.0	////	DRY	////	DRY	14.0	14.0	8.0	DRY	////	DRY
Turbidity (JTU)		500.+	280.0	330.0		98.0		0.0	0.0	30.0		22.0	
% Trans.		3.5	42.5	37.5		76.0		100.0	100.0	71.0		95.0	
Iron		////	1.15	0.72		0.40		////	0.02	0.04		0.00	
Nitrate		////	////	////		////		////	////	////		////	
Ortho-P		////	////	////		////		////	////	////		////	
Meta-P		////	////	////		////		////	////	////		////	
Surface °C		23.40	25.30	31.20		33.35		30.05	35.70	33.40		////	
Bottom °C		19.90	////	////		30.00		29.90	32.15	32.60		////	

Physico-chemical features of Pool 12, Tillman Co., Oklahoma

	1969		1970									
	6-XI	9-XII	21-I	13-III	22-IV	30-IV	26-V	1-VI	9-VI	3-VII	11-VIII	17-VIII
M-O Alk.				35.0		45.0		50.0	108.0		110.0	
Phen. Alk.				00.0		00.0		00.0	00.0		00.0	
Cal. Hard.				10.0		25.0		31.0	66.0		58.0	
Chloride				7.5		8.0		5.0	10.0		10.5	
TDS				39.0		57.0		83.0	165.0		127.0	
pH				7.10		6.85		6.88	8.57		7.86	
Oxygen	DRY	DRY	DRY	9.0	DRY	////	DRY	7.0	6.0	DRY	////	DRY
Turbidity (JTU)				92.0		500.+		500.+	500.+		52.0	
% Trans.				76.7		2.0		4.5	0.0		86.7	
Iron				0.28		////		////	0.10		0.05	
Nitrate				2.0		2.2		7.8	5.5		2.5	
Ortho-P				0.50		////		8.+	////		0.17	
Meta-P				0.02		////		8.+	////		0.10	
Surface °C				22.50		20.70		17.50	////		////	
Bottom °C				22.70		20.70		17.60	////		////	

Physico-chemical features of Pool 12, Tillman Co., Oklahoma

	1970				
	19-VIII	19-IX	3-X	1-XI	9-XII
M-O Alk.	305.0				
Phen. Alk.	00.0				
Cal. Hard.	151.0				
Chloride	15.0				
TDS	590.0				
pH	8.34				
Oxygen	10.0	DRY	DRY	DRY	DRY
Turbidity (JTU)	28.0				
% Trans.	92.8				
Iron	0.0				
Nitrate	2.7				
Ortho-P	0.03				
Meta-P	0.28				
Surface °C	31.20				
Bottom °C	31.20				

Physico-chemical features of Across Road 22 Pool, Tillman Co., Oklahoma

	1969			1970	1971
	23-VII	15-IX	6-XI	3-X	5-III
M-O Alk.	60.0	39.0	40.0	90.0	40.0
Phen. Alk.	00.0	00.0	00.0	00.0	00.0
Cal. Hard.	25.0	////	30.0	50.0	21.0
Chloride	////	////	////	5.0	11.0
TDS	72.0	65.0	44.5	112.0	51.0
pH	6.70	////	6.70	7.49	7.24
Oxygen	////	////	////	////	////
Turbidity (JTU)	122.0	415.0	500.+	48.0	41.0
% Trans.	70.0	29.5	1.7	87.1	89.7
Iron	0.45	////	////	0.06	0.05
Nitrate	////	////	////	////	4.0
Ortho-P	////	////	////	////	0.12
Meta-P	////	////	////	////	0.40
Surface °C	////	////	////	27.40	18.90
Bottom °C	////	////	////	24.30	18.35

Physico-chemical features of Pool 14, Tillman Co., Oklahoma

	1969										1970											
	28-III	10-V	23-V	VI	VII	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
M-O Alk.		37.0																				
Phen. Alk.		00.0																				
Cal. Hard.		////																				
Chloride		////																				
TDS		////											DRY ALL OF 1970									
pH		6.9																				
Oxygen	DRY	7.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY												
Turbidity (JTU)		500.+																				
% Trans.		5.0																				
Iron		////																				
Nitrate		////																				
Ortho-P		////																				
Meta-P		////																				
Surface °C / Bottom °C		24.70 / 23.20																				

Physico-chemical features of Pool 15, Tillman Co., Oklahoma
1969

	28-III	10-V	23-V	28-V	7-VI	17-VI	23-VI	24-VI	1-VII	9-VII	23-VII	2-VIII
M-O Alk.	DRY	62.0	WATER NOT TESTED	WATER NOT TESTED	195.0	70.0	110.0	////	85.0	DRY	DRY	DRY
Phen. Alk.		00.0			00.0	00.0	00.0	////	35.0			
Cal. Hard.		////			115.0	40.0	67.0	////	63.0			
Chloride		////			////	////	////	////	////			
TDS		////			////	////	242.0	////	162.0			
pH		6.4			8.14	7.3	6.78	////	10.0			
Oxygen		2.0			10.0	////	6.0	2.5	17.0			
Turbidity (JTU)		500.+			10.0	500.+	248.0	////	197.0			
% Trans.		8.5			97.5	11.5	46.5	////	55.0			
Iron		////			1.9	////	2.15	////	1.5			
Nitrate		////			0.0	////	////	////	1.5			
Ortho-P		////			0.57	////	////	////	0.52			
Meta-P		////			0.00	////	////	////	0.00			
Surface °C / Bottom °C		23.30 / 15.20			////	31.10 / 21.25	28.30 / 28.20	22.70 / 22.78	32.80 / 33.40			

Physico-chemical features of Pool 15, Tillman Co., Oklahoma

	1969				1970											
	15-IX	4-X	6-XI	9-XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
M-O Alk.	58.0	97.0														
Phen. Alk.	00.0	00.0														
Cal. Hard.	30.0	45.0														
Chloride	////	////														
TDS	82.0	120.0														
pH	7.45	6.97														
Oxygen	////	////	DRY	DRY												
Turbidity (JTU)	23.0	215.0														
% Trans.	94.5	52.6														
Iron	0.12	1.9														
Nitrate	////	////														
Ortho-P	////	////														
Meta-P	////	////														
Surface °C	////	////														
Bottom °C	////	////														

DRY ALL OF 1970

Physico-chemical features of Pool 16, Tillman Co., Oklahoma

1969

	28-III	10-V	23-V	28-V	29-V	7-VI	17-VI	24-VI	1-VII	9-VII	23-VII	2-VIII	15-IX
M-O Alk.		45.0		215.0	242.0		80.0	275.0					
Phen. Alk.		00.0		00.0	00.0		00.0	00.0					
Cal. Hard.		////		////	////		////	158.0					
Chloride		////		////	////		////	////					
TDS		////		////	////		////	354.0					
pH		7.10		8.48	7.37		7.5	7.44					
Oxygen	DRY	5.5	WATER NOT TESTED	10.0	10.0	DRY	4.5	////	DRY	DRY	DRY	DRY	DRY
Turbidity (JTU)		500.+		155.0	110.0		500.+	260.0					
% Trans.		21.5		63.0	73.2		8.0	45.2					
Iron		////		////	////		////	0.59					
Nitrate		////		////	////		////	////					
Ortho-P		////		////	////		////	////					
Meta-P		////		////	////		////	////					
Surface °C		23.80		33.70	33.45		32.85	////					
Bottom °C		23.70		32.55	31.70		27.10	////					

Physico-chemical features of Pool 16, Tillman Co., Oklahoma

	1969			1970											
	4-X	6-XI	9-XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
M-O Alk.	DRY	58.0	DRY	DRY ALL OF 1970											
Phen. Alk.		00.0													
Cal. Hard.		37.0													
Chloride		////													
TDS		////													
pH		7.15													
Oxygen		////													
Turbidity (JTU)		310.0													
% Trans.		38.0													
Iron		0.43													
Nitrate		////													
Ortho-P		////													
Meta-P		////													
Surface °C		////													
Bottom °C		////													

Physico-chemical features of Pool 17, Tillman Co., Oklahoma
1969

	28-III	10-V	23-V	28-V	29-V	7-VI	17-VI	23-VI	24-VI	1-VII	9-VII	23-VII	2-VIII
M-O Alk.	DRY	32.0	WATER NOT TESTED	53.0	62.0	81.0	35.0	60.0	////	77.0	320.0	130.0	120.0
Phen. Alk.		00.0		00.0	00.0	00.0	00.0	00.0	////	00.0	00.0	00.0	00.0
Cal. Hard.		////		////	////	55.0	////	42.0	////	50.0	195.0	55.0	50.0
Chloride		////		////	////	////	////	////	////	////	////	////	////
TDS		////		////	////	////	////	80.0	////	105.0	925.0	550.0	182.0
pH		7.20		7.75	7.37	7.10	7.20	6.65	////	7.23	8.45	8.75	7.50
Oxygen		5.0		6.0	7.0	8.0	7.0	6.0	7.0	////	////	6.5	////
Turbidity (JTU)		500.+		500.+	500.+	500.+	500.+	500.+	////	500.+	0.0	8.0	500.+
% Trans.		0.05		0.0	0.0	10.0	1.5	0.05	////	16.5	100.0	98.5	6.5
Iron		////		////	////	////	////	////	////	////	0.0	0.0	////
Nitrate		////		////	////	0.0	////	////	////	2.2	////	////	////
Ortho-P		////		////	////	0.65	////	////	////	1.13	////	////	////
Meta-P		////		////	////	0.42	////	////	////	0.50	////	////	////
Surface °C		22.15		28.35	33.15	////	26.20	26.60	21.80	31.80	34.50	////	////
Bottom °C		22.10		27.10	25.70	////	23.00	26.70	21.80	31.55	35.00	////	////

Physico-chemical features of Pool 17, Tillman Co., Oklahoma

	1969				1970								
	15-IX	4-X	16-XI	9-XII	21-I	13-III	22-IV	30-IV	26-V	1-VI	9-VI	2-VII	11-VIII
M-O Alk.	70.0	100.0	57.0			79.0		40.0		45.0		200.0	70.0
Phen. Alk.	00.0	00.0	00.0			00.0		00.0		00.0		00.0	00.0
Cal. Hard.	39.0	60.0	40.0			41.0		30.0		40.0		110.0	30.0
Chloride	////	////	////			12.5		10.0		5.0		17.5	17.0
TDS	90.0	140.0	95.0			138.0		40.0		38.0		800.0	107.0
pH	7.27	////	7.00			7.28		6.90		6.90		8.42	7.15
Oxygen	3.0	3.0	7.0	DRY	DRY	9.0	DRY	5.0	DRY	7.0	DRY	9.0	1.0
Turbidity (JTU)	220.0	500.+	298.0			196.0		500.+		500.+		0.0	265.0
% Trans.	51.2	2.8	39.7			55.0		0.05		0.05		100.0	43.9
Iron	0.15	////	0.62			0.10		////		////		0.06	0.09
Nitrate	////	////	////			4.0		7.0		0.55		20.00	1.1
Ortho-P	////	////	////			0.14		////		////		////	0.61
Meta-P	////	////	////			0.11		////		////		////	0.25
Surface °C	////	18.95	17.70			21.40		19.95		16.85		////	27.30
Bottom °C	////	18.90	13.70			14.05		18.80		16.85		////	////

Physico-chemical features of Pool 17, Tillman Co., Oklahoma
1970

	19-VIII	9-IX	3-X	1-XI	30-XII
M-O Alk.					
Phen. Alk.					
Cal. Hard.					
Chloride					
TDS					
pH	DRY	DRY	DRY	DRY	DRY
Oxygen					
Turbidity (JTU)					
% Trans.					
Iron					
Nitrate					
Ortho-P					
Meta-P					
Surface °C / Bottom °C					

Physico-chemical features of Pool 13
Tillman Co., Oklahoma

	1969			1970
	28-III	10-V	23-V to 30-XII	1-I through 31-XII
M-O Alk.		40.0		
Phen. Alk.		////		
Cal. Hard.		////		
Chloride		////		
TDS		////		
pH	DRY	6.65	DRY	DRY
Oxygen		4.5		
Turbidity (JTU)		500.+		
% Trans.		0.01		
Iron		////		
Nitrate		////		
Ortho-P		////		
Meta-P		////		
Surface °C / Bottom °C		25.90 / 25.90		

Physico-chemical features of Pool 18, Tillman Co., Oklahoma
1969

	28-III	10-V	23-V	28-V	7-VI	17-VI	23-VI	24-VI	1-VII	9-VII	23-VII	2-VIII	15-IX	4-X	6-XI
M-O.Alk.		33.0				31.0	////	73.0					40.0		40.0
Phen. Alk.		00.0				00.0	////	00.0					00.0		00.0
Cal. Hard.		////				////	////	63.0					30.0		35.0
Chloride		////				////	////	////					////		////
TDS		////				////	////	84.0					45.5		48.1
pH		7.5				7.48	6.72	////					////		7.05
Oxygen	DRY	////	DRY	DRY	DRY	////	5.5	5.0	DRY	DRY	DRY	DRY	////	DRY	////
Turbidity (JTU)		500.+				500.+	500.+	500.+					500.+		500.+
% Trans.		0.0				3.2	0.0	0.0					3.5		0.5
Iron		////				////	////	////					////		////
Nitrate		////				////	////	////					////		////
Ortho-P		////				////	////	////					////		////
Meta-P		////				////	////	////					////		////
Surface °C		23.30				30.25	24.95	21.50					////		////
Bottom °C		23.20				24.05	25.10	21.77					////		////

Physico-chemical features of Pool 18, Tillman Co., Oklahoma

	1969	1970											
	9-XII	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
M-O Alk.													
Phen. Alk.													
Cal. Hard.													
Chloride													
TDS													
pH													
Oxygen	DRY						DRY ALL OF 1970						
Turbidity (JTU)													
% Trans.													
Iron													
Nitrate													
Ortho-P													
Meta-P													
Surface °C / Bottom °C													

Physico-chemical features of Pool 19, Tillman Co., Oklahoma
1969

	28-III	10-V	23-V	29-V	7-VI	17-VI	24-VI	1-VII	9-VII	23-VII	2-VIII	15-IX	4-X
M-O Alk.		88.0				148.0							
Phen. Alk.		00.0				00.0							
Cal. Hard.		////				////							
Chloride		////				////							
TDS		////				////							
pH		7.10				6.98							
Oxygen	DRY	1.0	DRY	WATER NOT TESTED	DRY	////	DRY	DRY	DRY	DRY	DRY	DRY	DRY
Turbidity (JTU)		500.+				500.0							
% Trans.		3.2				21.0							
Iron		////				0.23							
Nitrate		////				////							
Ortho-P		////				////							
Meta-P		////				////							
Surface oC / Bottom oC		28.25 / 28.20				33.20 / ////							

Physico-chemical features of Pool 19, Tillman Co., Oklahoma

	1969		1970								
	6-XI	9-XII	21-I	13-III	22-IV	30-IV	26-V	1-VI	9-VI	30-VII	11-VIII
M-O Alk.	107.0			49.0		61.0	280.0	178.0			143.0
Phen. Alk.	3.0			00.0		00.0	00.0	00.0			00.0
Cal. Hard.	100.0			25.0		35.0	90.0	66.0			100.0
Chloride	////			5.0		6.0	165.0	75.0			5.5
TDS	525.0			57.0		71.0	800.0	390.0			153.0
pH	8.64			7.04		6.51	8.31	7.90			7.12
Oxygen	////	DRY	DRY	9.0	DRY	10.0	////	4.0	DRY	DRY	2.5
Turbidity (JTU)	90.0			277.0		500.+	42.0	142.0			129.0
% Trans.	77.3			42.2		22.2	89.5	65.0			68.3
Iron	0.21			0.45		////	0.00	0.16			0.12
Nitrate	////			2.0		3.5	9.0	3.0			2.7
Ortho-P	////			0.52		////	////	0.11			1.5
Meta-P	////			0.20		////	////	0.11			0.0
Surface °C / Bottom °C	//// / ////			21.05 / 17.00		21.30 / 20.73	//// / ////	17.10 / 17.00			33.60 / ////

Physico-chemical features of Pool 19, Tillman Co., Oklahoma

Physico-chemical features of Headgate Pool, Tillman Co., Oklahoma

	Pool 19, 1970					Headgate Pool, 1969			Headgate Pool, 1970		
	19-VIII	19-IX	3-X	1-XI	9-XII	2-VIII	15-IX	4-X	11-VIII	19-VIII	19-IX
M-O Alk.	DRY	DRY	DRY	DRY	DRY	141.0	50.0	110.0	120.0	DRY	DRY
Phen. Alk.						00.0	00.0	00.0	00.0		
Cal. Hard.						57.0	21.0	67.0	80.0		
Chloride						////	////	////	25.0		
TDS						203.0	78.0	172.0	200.0		
pH						7.00	8.33	7.18	6.62		
Oxygen						9.0	////	3.0	////		
Turbidity (JTU)						500.+	0.5	21.0	48.0		
% Trans.						18.3	98.7	95.3	87.9		
Iron						////	0.00	0.18	0.02		
Nitrate						2.25	////	////	3.0		
Ortho-P						0.075	////	////	0.02		
Meta-P						0.460	////	////	0.32		
Surface °C / Bottom °C						30.00 / ////	//// / ////	19.00 / 18.95	//// / ////		

Physico-chemical features of Pool 20, Tillman Co., Oklahoma
1969

	28-III	10-V	23-V	28-V	29-V	7-VI	17-VI	24-VI	1-VII	9-VII	23-VII	2-VIII	15-IX	4-X
M-O Alk.		40.0											40.0	48.0
Phen. Alk.		00.0											00.0	00.0
Cal. Hard.		////											15.0	40.0
TDS		////											52.0	77.0
pH		6.8											6.96	////
Oxygen	DRY	5.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	////	////
Turbidity (JTU)		500.+											52.0	500.+
% Trans.		3.5											91.0	9.9
Iron		////											0.08	////
Nitrate		////											////	////
Ortho-P		////											////	////
Meta-P		////											////	////
Surface °C / Bottom °C		25.6 / 25.3											//// / ////	//// / ////

Physico-chemical features of Pool 20, Tillman Co., Oklahoma

	1969		1970										
	6-XI	9-XII	21-I	13-III	22-IV	30-IV	26-V	1-VI	9-VI	2-VII	11-VIII	19-VIII	19-IX
M-O Alk.								70.0	247.0		75.0		
Phen. Alk.								00.0	00.0		00.0		
Cal. Hard.								50.0	125.0		32.0		
Chloride								7.5	12.5		5.0		
TDS								114.0	295.0		84.0		
pH								6.7	8.2		6.74		
Oxygen	DRY	DRY	DRY	DRY	DRY	DRY	DRY	////	////	DRY	////	DRY	DRY
Turbidity (JTU)								500.+	202.0		62.0		
% Trans.								0.05	54.0		84.1		
Iron								////	0.15		0.03		
Nitrate								////	2.5		2.2		
Ortho-P								////	////		4.22		
Meta-P								////	////		0.00		
Surface °C								////	////		32.8		
Bottom °C								////	////		31.9		

Physico-chemical features of Pool 20, Tillman Co., Oklahoma
1970

	3-X	1-XI	30-XII
M-O Alk.			
Phen. Alk.			
Cal. Hard.			
Chloride			
TDS			
pH			
Oxygen	DRY	DRY	DRY
Turbidity (JTU)			
% Trans.			
Iron			
Nitrate			
Ortho-P			
Meta-P			
Surface °C			
Bottom °C			

Physico-chemical features of Big Pearl Pool,
Comanche Co., Oklahoma
1970

	13-III	22-IV	30-IV	9-VI	Rest of 1970
M-O Alk.	70.0				
Phen. Alk.	00.0				
Cal. Hard.	52.0				
Chloride	10.0				
TDS	100.0				
pH	7.25				
Oxygen	9.0	DRY	DRY	DRY	DRY
Turbidity (JTU)	500.+				
% Trans.	18.0				
Iron	////				
Nitrate	2.0				
Ortho-P	1.8				
Meta-P	0.3				
Surface °C	21.95				
Bottom °C	21.95				

Physico-chemical features of Pool 21 (Mexican Pool), Tillman Co., Oklahoma

	1969										1970
	28-III	10-V	23-V	VI	VII	VIII	IX	X	XI	XII	I II III IV V VI VII VIII IX X XI XII
M-O Alk.		50.0									
Phen. Alk.		00.0									
Cal. Hard.		30.0									
Chloride		////									
TDS		////									
pH	DRY	7.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY ALL OF 1970
Oxygen		2.5									
Turbidity (JTU)		500.+									
% Trans.		4.1									
Iron		////									
Nitrate		0.80									
Ortho-P		0.69									
Meta-P		0.44									
Surface °C / Bottom °C		26.90 / 21.90									

Physico-chemical features of Pool 22, Tillman Co., Oklahoma

1969

	28-III	10-V	23-V	28-V	29-V	7-VI	17-VI	23-VI	1-VII	9-VII	23-VII	2-VIII	15-IX
M-O Alk.	////	27.0	61.0	74.0	100.0		30.0						
Phen. Alk.	////	00.0	00.0	00.0	00.0		00.0						
Cal. Hard.	////	////	////	////	////		10.0						
Chloride	////	////	////	////	////		////						
TDS	////	////	////	////	////		////						
pH	////	6.9	////	7.25	7.00		6.8						
Oxygen	////	4.0	////	1.0	1.0	DRY	////	DRY	DRY	DRY	DRY	DRY	DRY
Turbidity (JTU)	500.+	500.+	500.+	500.+	500.+		340.0						
% Trans.	5.0	22.0	4.5	0.0	0.0		35.5						
Iron	////	////	////	////	////		////						
Nitrate	////	////	////	////	////		////						
Ortho-P	////	////	////	////	////		////						
Meta-P	////	////	////	////	////		////						
Surface °C	////	24.90	////	31.60	33.80		////						
Bottom °C	////	20.60	////	31.10	33.70		////						

Physico-chemical features of Pool 22, Tillman Co., Oklahoma

	1969			1970									
	4-X	6-XI	9-XII	21-I	13-III	22-IV	30-IV	24-V	1-VI	9-VI	3-VI	11-VIII	19-VIII
M-O Alk.	50.0			15.0	25.0								
Phen. Alk.	00.0			00.0	00.0								
Cal. Hard.	18.0			5.0	7.5								
Chloride	////			5.0	5.0								
TDS	60.0			21.5	32.0								
pH	////			6.67	6.57								
Oxygen	////	DRY	DRY	////	6.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
Turbidity (JTU)	500.+			182.0	305.0								
% Trans.	0.0			57.5	38.7								
Iron	////			0.62	0.55								
Nitrate	////			6.0	3.7								
Ortho-P	////			////	0.10								
Meta-P	////			////	0.23								
Surface °C / Bottom °C	//// / ////			//// / ////	21.02 / 11.97								

Physico-chemical features of Pool 22, Tillman Co., Oklahoma

	1970				1971
	19-IX	3-X	1-XI	30-XII	5-III
M-O Alk.					29.0
Phen. Alk.					00.0
Cal. Hard.					16.0
Chloride					20.0
TDS					40.0
pH					6.91
Oxygen	DRY	DRY	DRY	DRY	////
Turbidity (JTU)					10.0
% Trans.					97.2
Iron					0.00
Nitrate					////
Ortho-P					////
Meta-P					////
Surface ^{o}C					18.80
Bottom ^{o}C					////

Physico-chemical features of Buffalo Pool, Comanche Co., Oklahoma

	1970								
	13-III	22-IV	30-IV	9-VI	VII	VIII	IX	X	XI
M-O Alk.	31.0	40.0	33.0						
Phen. Alk.	00.0	00.0	00.0						
Cal. Hard.	10.0	15.0	5.0						
Chloride	12.5	12.5	11.0						
TDS	55.0	81.0	55.0						
pH	7.15	7.50	7.20						
Oxygen	10.5	////	10.5	DRY	DRY	DRY	DRY	DRY	DRY
Turbidity (JTU)	59.0	40.0	97.0						
% Trans.	85.3	90.0	74.8						
Iron	0.05	0.03	0.16						
Nitrate	2.5	2.25	5.0						
Ortho-P	0.02	////	////						
Meta-P	0.13	////	////						
Surface ^{o}C	16.00	26.00	21.30						
Bottom ^{o}C	16.00	24.93	21.45						

Physico-chemical features of Swan Ranch Pool #1, Tillman Co., Oklahoma

	1969											1970
	17-VI	23-VI	24-VI	1-VII	9-VII	23-VII	2-VIII	15-IX	4-X	6-XI	9-XII	21-I
M-O Alk.	21.0	43.0	////	65.0	270.0	61.0	43.0	35.0	45.0	26.0		
Phen. Alk.	00.0	00.0	////	00.0	00.0	00.0	00.0	5.0	00.0	00.0		
Cal. Hard.	////	23.0	////	55.0	165.0	27.0	20.0	10.0	20.0	13.0		
Chloride	////	////	////	////	////	////	////	////	////	////		
TDS	////	41.0	////	78.0	600.0	77.5	55.0	37.0	57.0	39.0		
pH	7.35	7.05	////	////	////	7.28	8.18	8.58	6.79	7.30		
Oxygen	////	7.0	7.0	7.0	////	////	9.0	8.0	4.0	7.0	DRY	DRY
Turbidity (JTU)	500.+	500.+	////	500.+	500.+	249.0	82.0	0.0	14.0	72.0		
% Trans.	1.75	1.5	////	0.0	0.0	47.0	79.5	100.0	97.0	82.5		
Iron	////	////	////	////	////	0.72	0.38	0.11	0.12	0.32		
Nitrate	////	////	////	////	////	////	////	////	////	////		
Ortho-P	////	////	////	////	////	////	////	////	////	////		
Meta-P	////	////	////	////	////	////	////	////	////	////		
Surface °C	////	26.05	21.65	28.50	35.50	////	32.20	32.00	18.77	////		
Bottom °C	////	26.15	21.62	28.50	35.30	////	33.30	////	18.67	////		

Physico-chemical features of Swan Ranch Pool #1, Tillman Co., Oklahoma
1970

	13-III	22-IV	30-IV	26-V	1-VI	9-VI	2-VII	11-VIII	19-VIII	19-IX	3-X	1-XI	30-XII
M-O Alk.	22.0												
Phen. Alk.	00.0												
Cal. Hard.	9.0												
Chloride	7.0												
TDS	29.0												
pH	6.35												
Oxygen	9.0	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY	DRY
Turbidity (JTU)	185.0												
% Trans.	56.7												
Iron	0.22												
Nitrate	2.5												
Ortho-P	0.04												
Meta-P	0.30												
Surface °C / Bottom °C	23.70 / 23.20												

APPENDIX II

CIRCUMDIEL CYCLES OF SELECTED PHYSICO-CHEMICAL FEATURES OF WATERS FROM TEMPORARY POOLS IN SOUTHWESTERN AND CENTRAL OKLAHOMA

Circumdiel cycle of limnological conditions in Pool 3
on 5 to 6 June 1969

	5/VI/69			6/VI/69		
	12:20	16:20	20:30	00:45	07:25	11:30
Temperature (^{o}C)						
Air	31.50	33.20	25.80	19.70	18.70	31.70
Near edge, 2 cm deep						
North edge	32.20	30.32	24.35	20.45	17.90	31.45
South edge	28.10	30.20	23.80	20.10	17.50	27.80
East edge	31.40	31.90	23.65	20.49	17.85	30.30
West edge	28.70	31.60	24.12	20.15	18.15	26.60
Mid-pool, 6 cm deep						
Bottom	28.52	29.75	24.85	21.30	18.45	28.30
Chemical features (ppm)						
Oxygen	4.0	1.0	1.0	1.0	1.0	2.5

Circumdiel cycle of limnological conditions in Pool 2
on 5 to 6 June 1969

	5/VI/69			6/VI/69		
	12:45	16:40	20:50	01:15	07:45	11:49
Temperature (°C)						
Near edge, 2 cm deep						
North edge	35.95	35.40	24.45	18.80	17.70	34.90
West edge	36.60	35.50	24.65	19.65	18.40	34.95
East edge	35.40	34.20	24.65	19.05	18.00	34.55
Southwest edge	35.00	35.70	24.35	19.10	18.70	-----
Southeast edge	36.80	32.70	23.50	18.70	17.70	35.20
Air temperature	32.60	31.30	24.10	17.90	19.40	32.40
Chemical features (ppm)						
Oxygen	7.5	7.0	1.5	1.0	1.0	-----

Circumdiel cycle of limnological conditions in Pool 3
on 23 to 24 December 1969

	23/XII/69		24/XII/69		
	14:15	20:00	01:15	08:00	12:15
Temperature (°C)					
Air	16.50	3.00	0.00	1.50	7.50
Near edge, 2 cm deep					
North edge	13.10	5.63	2.20	2.10	6.75
South edge	8.80	2.80	1.55	0.95	8.10
East edge	14.45	6.40	1.60	1.85	7 40
West edge	10.18	4.58	1.53	1.25	7.05
Mid-pool, 15 cm deep					
Surface	11.45	7.05	3.55	1.45	6.45
Bottom	10.00	7.45	5.80	3.20	6.20
Chemical features (ppm except pH)					
Total alkalinity	25	22	21	21	15
Phenolphthalein alkalinity	0	0	0	0	0
Calcium hardness	10	----	----	----	10
Total dissolved solids	47.3	50.0	46.5	49.0	45.5
pH	6.44	6.45	6.40	6.32	6 37
Iron	1.85	----	----	----	0.51
Oxygen	4.0	4.5	4.0	3.0	4.0
Light penetration					
Transmittance (%)	59.0	----	----	----	72.7
Turbidity (JTU)	172.0	----	----	----	110.0

Circumdiel cycle of limnological conditions in Pool 1
on 23 to 24 December 1969

	23/XII/69		24/XII/69		
	13:30	20:40	02:00	07:45	13:00
Temperature (^{o}C)					
Air	17.00	3.00	1.00	2.00	10.00
Near edge					
North edge, 2 cm	14.45	5.50	1.80	1.50	8.63
South edge, 2 cm	14.10	5.40	1.50	1.30	7.80
West edge, 2 cm	14.85	4.52	1.50	1.90	8.95
East edge, 2 cm	10.40	3.90	1.75	1.35	7.80
Mid-pool, 10 cm deep					
Surface	13.80	6.00	2.30	1.85	8.53
Bottom	13.70	6.65	3.75	2.90	8.50
Chemical features (ppm except pH)					
Total alkalinity	75	80	75	80	75
Phenolphthalein alkalinity	0	0	0	0	0
Calcium hardness	49	----	----	----	52
Total dissolved solids	105	109	107	110	109
pH	8.27	8.10	8.00	8.05	8.05
Iron	0.25	----	----	----	0.13
Oxygen	10.5	9.0	8.0	8.0	10.0
Light penetration					
Transmittance (%)	58.5	----	----	----	58.5
Turbidity (JTU)	175.0	----	----	----	177.0

Circumdiel cycle of limnological conditions in Pool 11
on 28 to 29 May 1969

	28/V/69		29/V/69			
	15:30	20:25	03:00	07:00	10:45	12:45
Temperature (°C)						
Air	35.40	28.80	22.50	22.00	27.60	32.80
Near edge						
North edge, 2 cm	32.53	23.15	19.40	19.21	30.45	36.65
South edge, 2 cm	31.50	23.80	19.70	19.26	27.20	34.30
South edge, 5 cm	31.55	24.20	19.50	19.07	27.27	34.90
South edge, 8 cm	31.65	24.47	19.46	19.01	27.27	34.92
Mid-pool, 5 cm deep						
Surface	-----	24.30	19.50	18.97	27.27	34.55
Bottom	31.95	23.70	19.50	18.98	28.10	35.15
Chemical features (ppm except pH)						
Total alkalinity	173	-----	-----	215	-----	210
Phenolphthalein alkalinity	0	-----	-----	0	-----	0
Oxygen (mid-depth)	8.0	2.0	0.5	0.6	6.0	8.0
Iron	0.48	-----	-----	-----	-----	1.52
Light penetration						
Transmittance (%)	86.0	-----	-----	-----	-----	93.0
Turbidity (JTU)	58.0	-----	-----	-----	-----	37.0

Circumdiel cycle of temperature changes in Pool 1
on 19 to 20 September 1969

	19/IX/69		20/IX/69			
	16:30	22:15	02:15	07:15	11:15	15:00
Temperature (°C)						
Air	30.0	17.0	14.0	13.5	26.0	29.0
Near edge, 2 cm deep						
Northwest edge	32.8	22.7	19.9	18.0	28.7	32.7
North edge	32.2	23.0	20.7	18.3	28.0	32.5
Northeast edge	32.6	22.8	20.8	18.2	27.7	32.0
East edge	32.7	21.6	19.7	17.7	22.7	32.0
Southeast edge	32.2	22.8	19.4	18.1	26.9	32.7
South edge	31.1	23.8	21.3	18.5	27.4	32.1
Southwest edge	30.7	23.1	21.4	18.6	27.5	31.4
West edge	32.4	21.6	19.7	17.8	29.1	32.6
Mid-pool, 20 cm deep						
Surface	31.9	23.9	21.9	19.2	27.0	31.7
10 cm	29.4	23.9	21.9	19.2	25.6	30.2
Bottom	26.6	24.0	21.9	19.2	24.0	28.7

Circumdiel cycle of limnological conditions in Pool 2 on 9 to 10 April 1970

	9/IV/70	10/IV/70		
	18:25	01:00	07:30	13:00
Temperature (^{o}C)				
Air	16.00	13.20	13.00	26.00
Near edge, 2 cm deep				
North edge	17.05	12.60	10.87	27.95
South edge	17.30	12.25	11.00	28.20
East edge	16.85	11.55	10.45	27.50
West edge	16.40	11.90	10.57	26.80
Mid-pool, 10 cm deep				
Surface	18.05	13.30	11.15	27.50
Bottom	17.40	13.70	11.20	26.00
Total dissolved solids (ppm)				
Near edge, 2 cm deep				
North edge	42	50	50	50
South edge	42	50	55	50
East edge	42	50	50	45
West edge	45	60	55	45
Mid-pool, 10 cm deep				
Surface	41	50	50	48
Bottom	45	50	50	42
Chemical features (ppm except pH)				
Total alkalinity	30	----	40	38
Phenolphthalein alkalinity	0	----	0	0
Calcium hardness	20	----	25	22
Chloride	5	----	5	5
Oxygen	8.50	1.0	6.0	10.0
Light penetration				
Transmittance (%)	7.75	----	7.0	8.5
Turbidity (JTU)	500.+	----	500.+	500.+

Circumdiel cycle of limnological conditions in Pool 3
on 9 to 10 April 1970

	9/IV/70	10/IV/70		
	17:45	00:30	06:45	12:15
Temperature (°C)				
Air	23.00	16.10	8.50	24.50
Mid-pool, 10 cm deep				
Surface	19.70	14.30	10.10	27.00
Bottom	19.50	14.70	10.20	21.70
Mid-pool, 20 cm deep				
Surface	19.70	14.30	10.10	27.00
Bottom	18.00	15.20	10.30	18.20
Total dissolved solids (ppm)				
Mid-pool, 10 cm deep				
Surface	65	65	65	65
Bottom	--	70	70	70
Mid-pool, 20 cm deep				
Surface	65	65	65	65
Bottom	80	110	70	70
Chemical features (ppm except pH)				
Total alkalinity	40	45	43	45
Phenolphthalein alkalinity	0	0	0	0
Calcium hardness	20	22	25	20
pH	6.79	6.53	6.49	6.93
Oxygen (mid-depth)	6.0	1.0	1.5	6.5
Light penetration				
Transmittance (%)	46.1	48.5	50.0	48.0
Turbidity (JTU)	252	235	225	240

Circumdiel cycle of limnological conditions in Pool 1
on 5 April 1970

	5/IV/70			
	06:45	13:15	17:45	23:45
Temperature (^{o}C)				
Air	12.20	28.40	30.90	17.10
Near edge, 2 cm deep				
North edge	13.20	29.55	27.70	18.15
South edge	14.20	29.10	29.30	18.00
East edge	13.00	28.30	26.90	16.65
West edge	12.30	30.02	24.30	15.92
Mid-pool, 15 cm deep				
Surface	14.70	30.05	29.70	19.40
Bottom	14.81	27.00	29.40	19.65
Chemical features (ppm except pH)				
Total alkalinity	140	145	150	155
Phenolphthalein alkalinity	0	0	0	0
Calcium hardness	80	80	78	90
Total dissolved solids	149	150	190	190
pH	6.6	7.0	6.68	7.05
Chloride	7.5	7.5	10.0	10.0
Nitrate nitrogen	2.75	1.0	5.0	3.0
Oxygen (mid-depth)	5.0	7.0	5.5	2.0
Light penetration				
Transmittance (%)	9.5	9.5	4.75	8.0
Turbidity (JTU)	500.+	500.+	500.+	500.+

Circumdiel cycle of limnological conditions in Pool 3 on 5 to 6 March 1970

	5/IV/70			6/IV/70
	06:15	12:15	18:15	00:15
Temperature (°C)				
Air	12.20	28.40	30.90	17.10
Near edge, 2 cm deep				
North edge	13.80	25.00	22.80	17.90
South edge	12.80	29.00	24.30	17.80
East edge	12.90	32.90	24.90	16.80
West edge	13.20	30.00	21.80	17.00
Mid-pool, 15 cm deep				
Surface	14.60	30.50	25.00	19.50
7 cm	14.80	25.80	25.00	19.70
Bottom	14.90	24.10	25.00	19.70
Mid-pool, 20 cm deep				
Surface	14.60	30.50	25.00	19.10
7 cm	14.80	27.10	25.00	19.40
14 cm	14.90	23.40	24.90	19.70
Bottom	15.30	21.20	24.70	20.10
Total dissolved solids (ppm)				
Near edge, 2 cm deep				
North edge	61	55	57	62
South edge	70	63	57	73
East edge	62	63	60	85
West edge	69	58	61	70
Mid-pool, 15 cm deep				
Surface	54	52	55	60
Bottom	54	52	60	60
Mid-pool, 20 cm deep				
Surface	54	52	60	60
Bottom	54	52	65	60
Chemical features (ppm except pH)				
Total alkalinity	52	52	50	45
Phenolphthalein alkalinity	0	0	0	0
Calcium hardness	20	20	15	22
pH	6.94	6.95	6.70	6.60
Oxygen				
Surface	0.6	4.5	4.0	1.0
Bottom	0.6	3.0	2.5	0.8
Light penetration				
Transmittance (%)	49.5	59.0	40.0	61.0
Turbidity (JTU)	225.0	178.0	290.0	162.0

Circumdiel cycle of limnological conditions in Pool 1
on 9 to 10 April 1970

	9/IV/70		10/IV/70	
	17:00	23:35	06:15	11:30
Temperature (°C)				
Air	23.30	16.20	8.20	24.00
Near edge, 2 cm deep				
North edge	18.80	12.55	9.10	26.90
South edge	18.02	13.90	9.70	25.55
East edge	16.90	11.85	8.60	23.70
West edge	18.20	12.20	8.43	27.35
Mid-pool, 10 cm deep				
Surface	19.78	13.80	10.30	26.05
Bottom	19.80	14.21	10.33	21.60
Total dissolved solids (ppm)				
Near edge, 2 cm deep				
North edge	140	155	160	150
South edge	140	150	151	145
East edge	160	145	180	180
West edge	130	160	150	140
Mid-pool, 10 cm deep				
Surface	140	150	160	150
Bottom	150	155	160	145
Chemical features (ppm except pH)				
Total alkalinity	95	100	104	105
Phenolphthalein alkalinity	0	0	0	0
Calcium hardness	71	78	72	70
pH	8.45	8.20	7.83	8.40
Chloride	10.0	7.5	10.0	10.0
Iron	0.1	0.2	0.1	0.1
Light penetration				
Transmittance (%)	43.7	43.5	48.0	51.30
Turbidity (JTU)	265	260	240	220

Circumdiel cycle of limnological conditions in Pool 22
on 28 to 29 May 1969

	28/V/69		29/V/69			
	16:00	20:47	03:45	07:50	11:05	13:40
Temperature (^{o}C)						
Air	-----	26.60	22.30	22.00	30.40	34.80
Near edge						
East edge, 2 cm	31.30	23.37	19.69	19.88	24.67	35.20
West edge, 2 cm	31.35	23.00	19.76	19.85	24.65	34.00
West edge, 5 cm	31.80	23.20	19.68	19.67	24.05	33.70
Mid-pool, 7 cm deep						
Surface	31.60	23.40	19.76	19.67	23.85	33.80
Bottom	31.10	23.45	19.77	19.65	-----	-----
Chemical features (ppm except pH)						
Total alkalinity	74	-----	-----	80	-----	100
Phenolphthalein alkalinity	0	-----	-----	0	-----	0
Oxygen (mid-depth)	1.0	1.0	1.0	1.0	1.0	1.0
pH	7.25	-----	-----	6.82	-----	7.00
Light penetration						
Transmittance (%)	0.0	-----	-----	-----	-----	0.0
Turbidity (JTU)	500.+	-----	-----	-----	-----	500.+

Circumdiel cycle of limnological conditions in Pool 16
on 28 to 29 May 1969

	28/V/69		29/V/69			
	14:15	20:00	02:35	07:00	10:15	12:05
Temperature (°C)						
Air	32.10	30.40	22.80	21.00	26.20	32.50
Near edge						
North edge, 2 cm	33.80	25.55	19.80	18.80	27.35	34.53
South edge, 2 cm	32.10	26.49	20.22	19.05	25.05	33.20
South edge, 5 cm	33.30	26.15	19.82	18.77	25.08	33.25
Mid-pool, 6 cm deep						
Surface	33.70	24.80	19.74	18.70	26.13	33.45
Bottom	33.70	26.27	19.73	18.73	25.10	33.37
Mid-pool, 10 cm deep						
Surface	33.70	24.80	19.74	18.70	26.13	33.45
Bottom	32.55	26.10	20.22	19.10	21.90	31.70
Chemical features (ppm except pH)						
Total alkalinity	215.	.....	.....	245	.....	242
Phenolphthalein alkalinity	0	.....	.....	0	.....	0
Oxygen (mid-depth)	10.0	7.0	4.5	4.5	9.0	10.0
pH	8.48	......	.....	8.50	.....	7.37
Light penetration						
Transmittance (%)	63.0	.....	.....	.....	.....	73.2
Turbidity (JTU)	155.0	.....	.....	.....	.....	110.0

Circumdiel cycle of limnological conditions in Pool 17
on 28 to 29 May 1969

	28/V/69		29/V/69			
	14:45	20:10	02:50	07:15	10:25	12:18
Temperature (^{o}C)						
Air	32.10	29.40	23.20	22.00	28.10	32.30
Near edge						
East edge, 2 cm	28.10	24.50	19.00	19.35	25.90	32.40
West edge, 2 cm	28.40	24.72	20.20	19.48	26.05	32.40
West edge, 5 cm	28.75	25.12	20.20	19.29	25.05	31.00
Mid-pool, 10 cm deep						
Surface	28.35	25.05	20.10	19.08	25.95	33.15
Bottom	27.10	25.05	20.15	19.06	22.85	25.70
Chemical feature (ppm except pH)						
Total alkalinity	53	-----	-----	60	-----	62
Phenolphthalein alkalinity	0	-----	-----	0	-----	0
Oxygen (mid-depth)	6.0	6.0	6.0	6.0	7.0	7.0
pH	7.75	-----	-----	6.95	-----	7.37
Light penetration						
Transmittance (%)	0.0	-----	-----	-----	-----	0.0
Turbidity (JTU)	500.+	-----	-----	-----	-----	500.+

APPENDIX III

CHEMICAL FEATURES OF SOILS FROM DRY POOL BASINS AND THE SURROUNDING AREAS

Appendix III

Chemical features of soils from pool basins and surrounding areas.

The analyses conducted and the procedures followed for chemical determinations are listed below.

1. pH: Determined on saturated paste.
2. Nitrate Nitrogen: Extracted with water and determined with Orion Specific Ion Electrode.
3. Iron: Extracted with DTPA and determined by Atomic Absorption.
4. Total Dissolved Solids: Extracted with water and determined gravimetrically.
5. Hardness: Calculation based on Ca and Mg from water extracted for Total Dissolved Solids determination.
6. % $CaCO_3$: Neutralization of HCl and titration with NaOH. Example: Soil = 1.8% $CaCO_3$. This means that soil has 1.8% of the neutralizing potential of pure $CaCO_3$ or limestone. Converted to ppm, the soil would contain 18,000 ppm $CaCO_3$.
7. Phosphorus: Extracted with Bray's weak acid extractant and determined colorimetrically. This procedure is normally used for determining "available" phosphorus.

Chemical features of soil from the dry pool basins and surrounding areas of Pool 1 and Pool 2, Cleveland County, Oklahoma, and Pool 3, Pottawatomie County, Oklahoma.

	Pool 1			Pool 3			Pool 2	
	Area	Basin	Basin	Area	Basin	Basin	Area	Basin
Coll. date	12-69	12-69	7-70	12-69	12-69	7-70	7-70	7-70
pH	7.1	7.4	7.2	5.8	4.3	4.9	Sample Lost	6.4
Nitrate-N, ppm	5.0	8.0	12.0	5.0	5.0	12.0		5.0
Phosphorus, ppm	4.0	10.0	3.0	3.0	4.0	9.0		3.0
Iron, ppm	20.0	60.0	38.0	52.0	140.0	225.0		94.0
Hardness, ppm	80.0	285.0	195.0	40.0	50.0	40.0		85.0
% $CaCO_3$	1.3	2.9	0.3	0.7	2.0	0.0		0.0
Total Dissolved Solids (ppm)	700.0	1400.0	200.0	1400.0	1900.0	550.0		450.0

Chemical features of soil from the dry pool basins and surrounding areas of Pool 17 and Pool 21, Tillman County, Oklahoma.

	Pool 17			Pool 21		
	Area	Basin	Basin	Area	Basin	Basin
Coll. date	12-69	12-69	7-70	12-69	12-69	7-70
pH	7.3	7.1	7.4	7.3	6.8	7.2
Nitrate-N, ppm	20.0	53.0	8.0	7.0	14.0	16.0
Phosphorus, ppm	23.0	35.0	31.0	55.0	52.0	16.0
Iron, ppm	11.0	60.0	8.0	14.0	52.0	30.0
Hardness, ppm	125.0	475.0	105.0	135.0	135.0	140.0
% $CaCO_3$	1.1	1.8	0.0	1.2	1.5	0.0
Total Dissolved Solids (ppm)	600.0	1200.0	450.0	1100.0	900.0	600.0

Chemical features of soil from the dry pool basins and surrounding areas of Pool 11, Pool 12, and Pool 22, Tillman County, Oklahoma.

	Pool 11	Pool 12		Pool 22		
	Basin	Basin	Basin	Area	Basin	Basin
Coll. date	12-69	12-69	7-70	12-69	12-69	7-70
pH	7.3	7.5	7.0	6.1	5.1	5.7
Nitrate-N, ppm	15.0	16.0	31.0	5.0	41.0	5.0
Phosphate, ppm	58.0	51.0	2.0	26.0	30 0	43.0
Iron, ppm	57.0	59.0	14.0	66.0	162.0	68.0
Hardness, ppm	185.0	225.0	120.0	60.0	145.0	30.0
% $CaCO_3$	1.7	1.8	0.0	1.2	1.9	0.0
Total Dissolved Solids (ppm)	700.0	600.0	700.0	1100.0	1600.0	350.0

Chemical features of soil from the dry pool basins and surrounding areas of Pool 19, Pool 24, Power Pool, and Headgate Pool, Tillman County, Oklahoma.

	Pool 19 Basin	Pool 24 Basin	Power Pool Basin	Headgate Pool Basin
Coll. date	12-69	12-69	7-70	7-70
pH	6.7	7.2	7.3	6.9
Nitrate-N, ppm	23.0	13.0	6.0	52.0
Phosphorus, ppm	26.0	71.0	20.0	19.0
Iron, ppm	106.0	35.0	15.0	40.0
Hardness, ppm	235.0	195.0	115.0	270.0
% $CaCO_3$	1.7	2.2	0.3	0.4
Total Dissolved Solids (ppm)	900.0	800.0	350.0	900.0

APPENDIX IV

INVERTEBRATES FROM TEMPORARY POOLS

IN CENTRAL AND SOUTHWESTERN OKLAHOMA

INVERTEBRATES ASSOCIATED WITH TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

Invertebrates were identified by the use of Pennak (1953), Usinger (1968), Dillon and Dillon (1961), Bick and Bick (1957), Schaefer (1969) and Schaefer and Drew (1968, 1969). Some specimens were sent to various authorities for identification.

Subkingdom Protozoa
  Phylum Protozoa

Unidentified, but present in all pools

Subkingdom Metazoa
  Phylum Rotifera

Unidentified, but collected in Pools 1, 2, 3, 12 and Power Pool

Phylum Platyhelminthes
  Class Turbellaria
    Order Rhabdocoela

Unidentified, but collected in Pools 1, 3, 15, 16 and Across Road 22

Phylum Nematoda

Unidentified, but common in all pools

Phylum Mollusca
  Class Gastropoda

Physa virgata (Gould) - Pools 2, 3, 15 and 18

Lymnaea bulimoides (Lea) - Pool 1

Phylum Tardigrada
  Class Eutardigrada
    Order Macrobioloidea
      Family Macrobiotoidea

Hypsibius augusti (Murray) - Pool 1

Phylum Annelida
  Class Oligochaeta

Unidentified, but present in all pools

Phylum Arthropoda
Class Arachnida
Order Acarina

Water mites were collected only in Pool 3

Class Crustacea
Subclass Branchiopoda
Order Anostraca

Streptocephalus texanus Packard - Pools 18 and 22, Swan Ranch Pool, Power Station Pool, Across Road 22

Streptocephalus dorothae Mackin - Pool 22 and Power Station Pool.

Streptocephalus seali Ryder - Pool 2

Thamnocephalus platyurus Packard - Pool 22

Order Notostraca

Apus longicaudatus LeConte - Pools 18, 20 and 22

Order Diplostraca

Eulimnadia texana Packard - Pools 1, 2, 3, 11, 17, and 18

Eulimnadia antlei Mackin - Pool 1

Simocephalus exspinosus (Koch) - Pools 1, 2 and 3

Daphnia schodleri Sars - Pool 1

Moina wierzijskii - Pools 11, 16, 17, 18, Headgate Pool, Swan Ranch Pool, Long Swan Ranch Pool, Power Pool, and Short Swan Ranch Pool

Subclass Ostracoda
Order Podocopa

Cyprois sp. - Pool 1, 2 and 3

Unidentified - Pool 12

Subclass Copepoda
Order Cyclopoida

Eucyclops agilis Koch - Pools 1 and 3

Cyclops vernalis Fischer - Pools 1 and 3

Cyclops varicans rubellus Lilljeborg - Pool 3

Cyclops exilis Coker - Pool 2 and 3

Unidentified - all pools

Diaptomus clavipes Schacht. - Pool 2

Diaptomus siciloides Lillj. - Pool 2

Diaptomus saltillinus Brewer - Across Road 22

Subclass Malacostraca
Order Decapoda

Orconectes nais (Faxon) - Pool 1

Class Insecta
Order Collembola
Family Poduridae

Podura aquatica Linneaus - Pools 2, 3 and 12

Order Ephemeroptera
Family Baetidae

Callibaetis sp. - Pools 1, 2, 3, 11, and 15; Swan Ranch Pool.

Ameletus sp. - Pools 1, 3 and 12

Order Odonata
Suborder Anisoptera

Libellula sp. - Pool 2 and 3

Pantala sp. - Pool 15

Sympetrum sp. - Pool 3

Suborder Zygoptera

Lestes sp. - Pools 1, 2, 3 and 11

Ischnura sp. - Pool 1 and Swan Ranch Pool

Argia sp. - Pool 3

Order Hemiptera

Family Gerridae

Gerris marginatus Say - Pools 3 and 11

Trepobates subnitidus Esaki - Pool 1

Rheumatobates sp. - Pool 1

Family Veliidae

Microvelia sp. - Pools 2 and 3

Family Notonectidae

Notonecta undulata Say - Pool 11

Buenoa sp. - Power Station Pool and Swan Ranch Pool

Family Belostomatidae

Belostoma flumineum (Say) - Pools 2 and 17

Family Corixidae

Trichocorixa kanza Sailer - Power Station Pool

Sigara alternata (Say) - Pools 3, 11 and 15

Corisella edulis (Champion) - Pool 11

Family Gelastocoridae

Gelastocoris sp. - common around all pools

Order Coleoptera

Family Hydrophilidae

Subfamily Hydrophilinae

Tropisternus lateralis (Fabricius) - Pools 1, 2, 3, 11, 12, 15; Headgate Pool, Short Swan Ranch Pool, Power Station Pool

Hydrophilus triangularis Say - Pools 2, 11, 12, 16, 17; Swan Ranch Pool, Short Swan Ranch Pool, Across Road 22

Berosus striatus (Say) - Pools 11 and 12; Swan Ranch Pool

Subfamily Helophorinae

Helophorus lineatus Say - Pools 3 and 18

Family Gyrinidae

Dineutes assimilis Kirby - Pools 3, 11, 12; Swan Ranch Pool

Gyrinus parcus Say - Pool 11

Family Dytiscidae

Agabus disintegratus (Crotch) - Pools 2 and 3

Copelatus sp. - Pools 1, 11, 3, 18; Swan Ranch Pool

Laccophilus fasciatus Aube' - Pools 1, 3, 12; Across Road 22

Thermonectus basillaris Harris - Pools 1, 3, 12, 17; Power Station Pool, Short Swan Ranch Pool

Eretes sticticus (L.) - Pool 12, Headgate Pool

Coptotomus interrogatus (Fabricius) - Pools 1 and 2

Hydroporus sp. - Pool 2

Order Diptera
Family Culicidae

Aedes sp. - Pools 3, 11, 12, and 15

Chaoborus sp. - Pools 2 and 3

Family Chironomidae

Unidentified - common in all pools

Family Sciomyzidae

Unidentified - Pool 1

Order Orthroptera
Family Gryllacrididae

Daihinia brevipes Haldeman - common around all Tillman County temporary pools

APPENDIX V

AMPHIBIANS AND REPTILES ASSOCIATED WITH TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

AMPHIBIANS AND REPTILES ASSOCIATED WITH TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

All adult reptiles and amphibians were identified by the use of Conant (1958), Webb (1970), and Bragg et. al. (1950). Larval amphibians were identified by the use of Bragg (1950) and Altig (1970).

Class Amphibia
  Order Anura
    Family Pelobatidae

Scaphiopus couchi - all pools in Tillman County

Scaphiopus bombifrons - Pools 1, 4 and 5 in Cleveland County, all pools in Tillman County

Scaphiopus holbrooki hurteri - Pools 1, 2 and 3

Family Bufonidae

Bufo cognatus - around Pool 1, bred in Donut Pool

Bufo woodhousei woodhousei - around Pool 1 and in Swan Ranch Pool

Bufo americanus charlesmithi - bred in Pools 1, 2 and 3

Bufo compactilus speciosus - common near all Tillman County pools

Family Ranidae

Rana pipiens - bred in all central Oklahoma pools, occasionally in Tillman County pools

Family Microhylidae

Gastrophryne olivacea olivacea - bred in all central Oklahoma pools, occasionally in Tillman County pools

Family Hylidae

Acris crepitans blanchardi - bred in all central Oklahoma pools

Acris gryllus gryllus - occasionally found around Tillman County pools.

Hyla versicolor - bred in all central Oklahoma pools

Pseudacris triseriata triseriata - bred in Pool 3

Pseudacris triseriata feriarum - collected in Swan Ranch Pool

Pseudacris clarki - bred in Pools 1 and 2

Pseudacris streckeri - bred in all central Oklahoma pools

Class Reptilia
Order Testudinata
Family Chelydridae

Chelydra serpentina serpentina - Pool 3

Family Kinosternidae

Kinosternon flavescens flavescens - Pools 15, 16 and 20

Family Testudinidae

Terrapene ornata ornata - Pool 2 and near all pools in Tillman County.

Terrapene carolina triunguis - Pool 2

Order Squamata
Family Iguanidae

Sceloporus undulatus undulatus - Pool 3

Phrynosoma cornutum - common near Tillman County pools

Family Teiidae

Cnemidophorus sexlineatus - Pools 3 and 22

Family Scincidae

Lygosoma laterale - Pool 3

Order Serpentes

Family Colubridae

Regina grahami - Pool 22

Thamnophis sirtalis parietalis - Pool 3

Thamnophis sauritus proximus - Pools 2 and 3

Haldea striatula - Pool 3.

Masticophis flagellum testaceus - Pool 22

Pituophis melanoleucus sayi - throughout Tillman County

Lampropeltis calligaster calligaster - Pool 12

Rhinocheilus lecontei tessellatus - Swan Ranch Pool

Family Viperidae

Agkistrodon contortrix laticinctus - Pool 3

APPENDIX VI

VASCULAR PLANTS ASSOCIATED WITH TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

VASCULAR PLANTS ASSOCIATED WITH TEMPORARY POOLS IN CENTRAL AND SOUTHWESTERN OKLAHOMA

Plants were identified by the use of Goodman (1958) and Waterfall (1969).

FAMILY MARSILIACEAE

Marsilea mucronata A. Br. Pool 15

FAMILY PINACEAE

Juniperus virginiana L. Pool 1

FAMILY GRAMINEAE

Agrostis hyemalis (Walt.) BSP. Pool 3
Andropogon saccharoides Sw. Pool 1
Cenchrus incertus M. A. Curtis Swan Ranch Pool
Diplachne fascicularis (Lam.) Beauv. Pool 1
Echinochloa colonum (L.) Link, forma colonum Pools 1 and 3; Swan Ranch Pool; Pool 15
Hordeum pusillum Nutt. Pool 22
Panicum anceps Michx. Pool 2

FAMILY CYPERACEAE

Cyperus ovularis (Michx.) Torr., var. ovularis Pools 2 and 3
Cyperus strigosus L. Pool 3
Cyperus virens Michx. Pools 2 and 3
Eleocharis Engelmannii Steud. Pools 2 and 3
Eleocharis obtusa (Willd.) Schultes, var. obtusa Pools 1, 2 and 3

FAMILY COMMELINACEAE

Commelina virginica L. Swan Ranch Pool
Tradescantia occidentalis (Britt.) Smyth Swan Ranch Pool
Tradescantia ohiensis Raf., forma ohiensis Pool 3

FAMILY PONTEDERIACEAE

Heteranthera limosa (Sw.) Willd.   Pools 1 and 3

FAMILY JUNCACEAE

Juncus diffusissimus Buckl.   Pools 2 and 3
Juncus interior Wieg.   Pool 3

FAMILY LILIACEAE

Nothoscordum bivalve (L.) Britton   Pools 1 and 3
Ornithogalum umbellatum L.   Pool 1

FAMILY IRIDACEAE

Sisyrinchium campestre Bicknell, forma *campestre*   Pool 1

FAMILY SALICACEAE

Populus deltoides Marsh.   Pool 1
Salix nigra Marsh.   Pool 2

FAMILY FRAGACEAE

Quercus marilandica Muenchh.   Pool 3
Quercus stellata Wang.   Pools 2 and 3

FAMILY ULMACEAE

Ulmus sp.   Pool 1

FAMILY POLYGONACEAE

Polygonum pensylvanicus L.   Pool 22
Polygonum aviculare L.   Pools 17 and 22
Polygonum hydropiperoides Michx.   Pools 2 and 3
Rumex altissimus Wood   Pool 3

FAMILY CHENOPODIACEAE

Chenopodium leptophyllum Nutt.   Pool 3

FAMILY AMARANTHACEAE

Froelichia gracilis (Hook.) Moq.   Swan Ranch Pool

FAMILY AIZOACEAE

Mollugo verticillata L.   Swan Ranch Pool

FAMILY PORTULACACEAE

Talinum parviflorum Nutt. Pool 1

FAMILY CAROPHYLLACEAE

Arenaria serpyllifolia L. Pool 3

FAMILY RANUNCULACEAE

Anemone caroliniana Walt., forma *violacea* Clute Pool 3

FAMILY PAPVERACEAE

Argemone polyanthemos (Fedde) G. B. Ownb. Pools 17 and 22

FAMILY CRUCIFERAE

Capsella bursa-pastoris (L.) Medic. Pool 19
Descurainia pinnata (Walt.) Britt. var. *brachycarpa* (Richards) Fern. Pool 19
Dithyrea Wislizenii Engelm. var. *Palmeri* Payson Power Station Pool
Erysimum repandum L. Pool 19
Lepidium austrinum Small Pool 11
Lepidium virginicum L. Pools 3 and 11
Sibara virginica (L.) Rollins Pool 19

FAMILY ROSACEAE

Rubus thrysanthus Focke Pool 3

FAMILY LEGUMINOSAE

Astragalus Lindheimeri Gray Pool 22
Cassia fasciculata Michx. Pool 1, 2 and 3
Cercis canadensis L., forma *glabrifolia* Fern. Pool 1
Petalostemum purpureum (Vent.) Rydberg Pools 1 and 2
Desmodium canescens (L.) DC. Pools 1 and 2
Indigofera miniata Ortega, var. *leptosepala* (Nutt.) Turner Pools 1 and 2
Krameria lanceolata Torr. Pool 1
Lespedeza striata (Thunb.) H. & A. Pool 3
Melilotus alba Desv. Swan Ranch Pool
Prosopis juliflora (Swartz) DC., var. *glandulosa* (Torr.) Cock. Pool 18
Schrankia uncinata Willd. Pool 22

FAMILY ZYGOPHYLLACEAE

Tribulus terrestris L. Swan Ranch Pool

FAMILY EUPHORBIACEAE

Cnidoscolus texanus (Muell. Arg.) Small   Pool 3
Croton glandulosus L., var. *septentrionalis* Muell. Arg.   Pools 1, 2 and 3

FAMILY ANACARDIACEAE

Rhus copallina L., var. *latifolia* Engler   Pools 1 and 2
Rhus Toxicodendron L., forma *leiocarpa* Fern.   Pool 3

FAMILY MALVACEAE

Callirhoe involucrata (Nutt. ex Torr.) Gray, var. *involucrata*
Pool 1

FAMILY TAMARICACEAE

Tamarix gallica L.   Pool 22

FAMILY CISTACEAE

Lechea tenuifolia Michx.   Pool 3

FAMILY VIOLACEAE

Viola missouriensis Greene   Pool 1

FAMILY PASSIFLORACEAE

Passiflora incarnata L., forma *incarnata*   Pool 3

FAMILY LYTHRACEAE

Ammannia auriculata Willd., var. *arenaria* (H.B.K.) Koehne
Pools 1 and 2

FAMILY ONAGRACEAE

Gaura sinuata Nutt.   Power Station Pool
Gaura villosa Torr., var. *arenicola* Munz   Power Station Pool
Ludwigia alternifolia L. var. *alternifolia*   Pool 2
Ludwigia palustris (L.) Ell., var. *americana* (DC.) Fern. & Grisc.
Pool 3
Oenothera heterophylla Spach, var. *rhombipetala* (Nutt.) Fosberg
Pool 3, Swan Ranch Pool
Oenothera laciniata Hill, var. *grandiflora* (Wats.) Robinson
Swan Ranch Pool
Oenothera serrulata Nutt.   Pool 1

FAMILY UMBELLIFERAE

Daucus pusillus Michx.   Pools 1 and 2

FAMILY CORNACEAE

Cornus Drummondii Meyer Pool 1

FAMILY GENTIANACEAE

Sabatia campestris Nuttall, forma campestris Pools 1, 2 and 3

FAMILY ASCLEPIADACEAE

Asclepias tuberosa L. Pool 3, Power Station Pool

FAMILY CONVOLVULACEAE

Cuscuta sp. Pool 17

FAMILY HYDROPHYLLACEAE

Phacelia strictiflora (Engelm. & Gray) Gray. var. Lundelliana Constance Swan Ranch Pool, Pool 12

FAMILY BORAGINACEAE

Heliotropium tenellum (Nutt.) Torr. Pool 1
Lithospermum arvense L. Pool 19
Lithospermum incisum Lehm. Pool 1

FAMILY VERBENACEAE

Verbena bipinnatifida Nutt. Pool 22
Verbena pumila Greene Pool 19
Verbena stricta Vent., forma stricta Pool 2

FAMILY LABIATAE

Lamium amplexicaule L., forma amplexicaule Pool 19
Monarda citriodora Cerv. ex Lagasca Pool 22
Monarda punctata L., var. occidentalis (Epl.) Palm. & Steyerm. Power Station Pool
Teucrium canadense L., var. canadense Pool 1
Teucrium laciniatum Torr. Pool 22

FAMILY SOLANACEAE

Physalis lobata Torrey, var. lobata Power Station Pool
Solanum elaeagnifolium Cav. forma elaeagnifolium Pool 17

FAMILY SCROPHULARIACEAE

Linaria canadensis (L.) Dumont, var. texana (Scheele) Pennell Pool 2
Penstemon Cobaea Nuttall Pool 1

FAMILY PLANTAGINACEAE

Plantago aristata Michx. Pool 3
Plantago Purshii R. & S., var. Purshii Pools 1 and 3
Plantago virginica L. Pools 1 and 3

FAMILY RUBIACEAE

Diodia teres Walt., var. setifera Fern. & Grisc. Pools 1 and 3
Hedyotis nigricans (Lam.) Fosb. Pool 1

FAMILY CAPRIFOLIACEAE

Sambucus canadensis L., var. canadensis Pool 2
Symphoricarpos orbiculatus Moench Pools 1 and 3

FAMILY CUCURBITACEAE

Cucurbita foetidissima H.B.K. Swan Ranch Pool

FAMILY CAMPANULACEAE

Specularia Holzingeri (McVaugh) Fern. Pools, 2, 11 and 12; Swan Ranch Pool

FAMILY COMPOSITAE

Achillea lanulosa Nutt., forma lanulosa Pool 1
Ambrosia psilostachya DC., var. Lindheimeriana (Scheele) Blankenship Pool 3
Aphanostephus skirrhobasis (DC.) Trel. Swan Ranch Pool
Aster Luecelene Blake Swan Ranch Pool, Power Station Pool
Aster ericoides L. Pool 2
Centaurea americana Nutt. Swan Ranch Pool
Chaetopappa asteroides DC. Pool 3
Chrysopsis villosa (Pursh) Nutt., var. stenophylla Gray Pools 2 and 3
Cirsium sp. Swan Ranch Pool
Coreopsis tinctoria Nutt., forma tinctoria Pools 2 and 22
Echinacea augustifolia DC., var. angustifolia Pool 22
Erigeron strigosus Muhl. ex Willd. Pool 3
Gaillardia pulchella Foug. Power Station Pool
Gaillardia suavis (Gray & Engelm.) Britt. & Rusby Power Station Pool
Gutierrezia dracunculoides (DC.) Blake Pool 1
Helianthus petiolaris Nutt. Swan Ranch Pool
Hymenoxys scaposa (DC.) Parker, var. linearis (Nuttall) Parker Swan Ranch Pool
Hymenoxys linearifolia Hook. Power Station Pool
Lindheimera texana Gray & Engelm. Power Station Pool
Ratibida columnifera (Nutt.) E. & S., forma columnifera Pool 1
Rudbeckia amplexicaulis Vahl. Pool 22
Rudbeckia hirta L., var. pulcherrim Farwell Pools 1 and 2

Solidago sp. Pool 2
Thelesperma ambiguum Gray Pools 1 and 2
Vernonia Bladwinii Torr., var. *Baldwinii* Pools 1, 2 and 3